University of Southern Queensland
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The effect of lighting interchange ramps on safety – A study of the M1

A dissertation submitted by

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ABSTRACT

The implementation of street lighting throughout the world varies greatly on road networks particularly at grade separate interchanges. The safety benefit of street lighting on grade separated interchange ramps was analysed to determine the effect of street lighting on interchange exit and entry ramps be it positive or negative.

Interchange ramps along the Sydney to Newcastle M1 were inspected to determine the current lighting layout and classified as complete interchange lighting (CIL), partial interchange lighting (PIL) or no lighting. The crash data along each ramp were analysed to determine any relationships. The independent variables included natural lighting, crash type, crash severity, weather conditions and other contributing factors. The analysis was used to determine whether additional or less lighting may have prevented accidents or was not related to safety outcomes.

Nine interchanges along the Sydney to Newcastle M1 were selected in the study with 419 crashes recorded and analysed in diverge and merge areas. There was a 50% split of accidents occurring on exit and entry ramps, with 66% of all accidents occurring during the day. Exit ramps have the most crashes at night with 32% of crashes on exit ramps occurring at night.

Lighting exit ramps was found to reduce the number of accidents occurring and saw a 200% and 52% reduction in fatality and injury accidents respectively compared to unlit exit ramps, a cost benefit of 3.2 was determined indicating that lighting exit ramps is a reasonable and economical safety measure. The results for interchange entry ramps and providing street lighting in the merge area indicate that the safety benefit from street lighting was minimal.

LIMITATIONS OF USE

CERTIFICATION

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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GLOSSARY

Acceleration lane	An auxiliary lane used to allow vehicles to increase speed without interfering with the main traffic stream. It is often used on the departure side of intersections
Alignment	The geometric form of the centreline (or other reference line) of a carriageway in both the horizontal and vertical directions.
Annual average daily traffic (AADT)	The total volume of traffic passing a roadside observation point over the period of a calendar year, divided by the number of days in that year (365 or 366 days).
Auxiliary lane	A portion of the carriageway adjoining the through traffic lanes, used for speed change or for other purposes supplementary to through traffic movement.
Arterial road	A road that predominantly carries through traffic from one region to another, forming principal avenues of travel for traffic movements.
Arterial road (rural)	A general term for the main road carrying mostly long-distance traffic, as distinct from local traffic.
Benefit/cost ratio (BCR)	The ratio of the discounted benefits over the life of a project to the discounted capital costs, or the project's discounted total agency costs.
Carriageway	That portion of a road or bridge devoted particularly to the use of vehicles, inclusive of shoulders and auxiliary lanes.
Continuity line	A longitudinal broken line of distinctive pattern, which may be used to indicate the edge of that portion of a carriageway assigned to through traffic and which is intended to be crossed by traffic turning at an intersection, or entering or leaving a freeway at an interchange.
Crash	An apparently unpremeditated event, which results in death or injury to a person or property damage and is attributable to the movement of a road vehicle on a public road (including vehicles entering or leaving a public road).
Crash rates	A crash rate is a ratio of the number of crashes to some common denominator, usually vehicle kilometres travelled, head of population or period of time. Crash rates allow more meaningful comparisons to be made between crash locations.
Deceleration lane	An auxiliary lane provided to allow vehicles to decrease speed.
Design	Can mean design of a scheme, installation, treatment or device. The distinction is important, and should be made clear in each case.

Design standard Identifies particular standards used in the design, e.g. standard lane width.

Diverging The dividing of a single stream of traffic into separate streams.

Driver fatigue Concentration and/or discomfort can lead to problems with fatigue including: slow reactions and decisions; slow control movements; hallucinations; decreased tolerance for other road users; poor lane tracking and maintenance of headway speed; and loss of situational awareness. Because fatigue is not easily quantifiable, the importance of fatigue as a cause of crashes is almost certainly underestimated in crash investigations.

Embankment A construction (usually of earth or stone) to raise the ground (or formation) level above the natural surface.

Entry ramp A carriageway to allow vehicles to enter a freeway, motorway or expressway.

Exit ramp A carriageway to allow vehicles to leave a freeway, motorway or expressway.

Freeway A divided highway with no access for traffic between interchanges and with grade separation at all intersections.

Gore A triangular area where two roads either meet or split.

Grade 1. A length of carriageway sloping longitudinally. 2. The rate of longitudinal rise (or fall) of a carriageway with respect to the horizontal, expressed as a percentage. 3. To design the longitudinal profile of a road.

Grade separation The separation of road, rail or other traffic so that crossing movements, which would otherwise conflict, are at different elevations.

Illuminance The physical measure of illumination is illuminance. It is the luminous flux arriving at a surface divided by the area of the illuminated surface. Unit: lux (lx); 1 lx = 1 lm/m^2

Lumiance The physical quantity corresponding to the brightness of a surface (e.g. a lamp, luminaire or reflecting material such as the road surface) when viewed from a specified direction.

Manoeuvre Any action on the part of a driver with regard to merging, weaving or overtaking.

Manoeuvre area The area in which merging, weaving, or overtaking movements occur.

Merging	The converging of separate streams of traffic into a single stream.
Raised reflective pavement markers (RRPMs)	A white or coloured retro-reflective device attached to the surface of the road pavement.
Ramp	1. A circulation roadway that connects an access driveway to an off street car park on a substantially different level or that connects two levels in a multi-level car park. 2. Carriageway within an interchange providing for travel between two arms (legs) of the intersecting roads
Road	Link in the network, which exists to carry traffic reasonably efficiently, on which severe traffic restraint is inappropriate (includes ‘arterials’, ‘main roads’ and other traffic routes).
Road safety engineering	A competence and experience in the investigation and analysis of crash locations and the design of effective remedial engineering treatments.
Run-off crashes	Are described as vehicles leaving or straying off the travel lane(s) and striking an off-road object or overturning off the road.
Rural motorway	A motorway connecting urban and industrial areas that are some considerable distance apart.
Sight distance	The distance, measured along the road over which visibility occurs between a driver and an object or between two drivers at specific heights above the carriageway in their lane of travel.1. Minimum gap sight distance (MGSD) The minimum sight distance based on the gap necessary to perform a particular movement. 2. Entering sight distance (ESD) The sight distance required for minor road drivers to enter a major road via a left or right turn, such that traffic on the road is unimpeded.
Street light	Lamps that are generally erected on poles along a street to illuminate the immediate area.
Through lane	A lane provided for the use of vehicles proceeding straight ahead.
Vehicles per day (VPD)	The number of vehicles observed passing a point on a road in both directions for 24 hours.
Vertical alignment	The longitudinal profile along the design line of a road.

1. INTRODUCTION

Street Lighting standards are used throughout the world by local government councils, state government authorities and private consultants to provide sufficient lighting that facilitates in safe driver movements, satisfies pedestrian visual requirements and discourages illegal acts. The standards vary across the globe with different interpretations and implementations, however the engineering principal remains the same.

A review of standards nationally and internationally will be undertaken to get an understanding and appreciation for lighting practices on interchange exit and entry ramps.

This report looks closely at interchange ramp accident history to understand the crash characteristics and types of crashes that commonly occur on interchange exit and entry ramps, regardless if lighting is provided on not.

Typical lighting installations will be looked at to determine from previous studies if different levels of lighting installed on interchange ramps have affected accident rates. Levels of lighting to be looked at include complete lighting, partial lighting and no lighting of interchange entry and exit ramps.

The safety benefit of street lighting as an accident reduction measure varies around the world ranging from 13 – 75%. Previous studies conducted around the world will be looked at to discover the most widely used safety figure for street lighting and how it compares to the safety benefit of street lighting used in New South Wales. The installation and maintenance cost for street lighting on New South Wales highways, particularly interchanges, will be looked at to show the spectrum of ranging costs from project to project. This inturn makes the safety benefit to cost benefit of installing street lighting even more of an unknown.

The implementation of street lighting throughout the world varies greatly on road networks particularly grade separate interchanges. Grade separated interchanges along the Sydney to Newcastle Motorway (M1) in New South Wales will be looked at closely with the configuration of the street lighting at the entry and exit ramps also referred to as the diverge and merge points being the particular focus.

The M1 was selected due to its inconsistent street lighting layouts at grade separated interchange exit and entry ramps, the high volume of traffic and availability of accident records. On the 16 interchanges along the M1 the ramp lighting provided varies from being completely lit, partially lit to no lighting.

The goal of this thesis is to determine whether interchanges that are lit according to the standard are safer than those that are not. Crash data from the NSW road crash database at each interchange will be analysed and compared.

2. LITERATURE REVIEW

A literature review has been undertaken as part of this project to provide information about previous research related and deemed appropriate to this topic. Information has been sought from New South Wales Government departments, interstate governing bodies and globally to gain an understanding of the current standards and practices for design and installation of street lighting at grade separated interchanges and how the standards have developed and changed over time.

Accident history on interchange ramps will provide a key insight into the crash characteristics and types of crashes that commonly occur on interchange entry and exit ramps and are associated with diverge and merge manoeuvres.

Researching the safety benefits of street lighting and different levels of street lighting provided on interchange entry and exit ramps, will enable this paper to find out what level of lighting provides the optimum results both economically and in accident reduction.

Installation and maintenance cost for street lights in New South Wales will be documented to understand the varying costs associated with lighting and the potential savings that could be made through the reduction of lights provided on grade separated interchange ramps.

Information from this literature review will then allow for a suitable method of measuring the safety benefits of street lighting to determine the affect lighting on interchange ramps on the M1 has on safety.

2.1 STANDARDS IN AUSTRALIA

In Australia the controlling document for lighting of roads and public spaces is Australian/ New Zealand Standard (AS/NZS) 1158.0. However each state and territory has developed their own lighting standards that satisfy their requirements. Local councils have their own guidelines. This research will not explore council standards, as it is limited to state and federal level road networks and the street lighting provided on grade separated interchange entry and exit ramps.

Australian/ New Zealand Standard 1158.0 Lighting for roads and public spaces is broken up into six parts. These cover vehicular traffic, pedestrian area lighting, pedestrian crossing lighting, calculation requirements and lighting definitions and technical specifications. The performance criteria for road and public space lighting schemes can include any or all of the three basic aims of—

a) Facilitation of safe movement.

b) The discouragement of illegal acts and

c) Contributing to the amenity of an area through increased aesthetic appeal.

However the most common requirement for a lighting scheme is to allow for the safe movement of people. Therefore the series divides road lighting into the two following broad categories:

1) Category V lighting - Lighting that is applicable to roads on which the visual requirements of motorists are dominant. e.g. traffic routes.

2) Category P lighting - Lighting that is applicable to roads and other outdoor public spaces on which the visual requirements of pedestrians are dominant, e.g. local roads, outdoor shopping precincts, outdoor car parks.

For the purpose of this research, Category V lighting, AS/NZS 1158.1.1 and 1158.1.2 will be looked at in detail, as these are the sections concerned with road traffic. The other sections will not be covered in detail, as they are less applicable to the issue.

The objective of road lighting (Category V) is to provide a sufficiently lit environment that will enhance safety and provide comfortable conditions for vehicular and pedestrian movements at night, whilst maintaining the integrity of the night environment.

Category V lighting is broken into five subcategories as shown in Table 1, an extracted table from AS/NZS 1158.1.1. The five categories are determined by different operating characteristics such as traffic volume, pedestrian volume, speed environment and road classification.

Table 1: AS/NZS 1158.1.1 Category V Subcategories

CATEGORY V LIGHTING AND TYPICAL APPLICATIONS		
Typical applications		Lighting subcategory
Description of road	**Operating characteristics**	
Arterial or main roads in central and regional activity centres of capital and major provincial cities, and other areas with major abutting traffic generators	Mixed vehicle and pedestrian traffic High to very High vehicle volume High to very High pedestrian volume Moderate to low vehicle speeds Stationary vehicles alongside the carriageway Through and local traffic High traffic generation from abutting properties	V1
Arterial roads that predominantly carry through traffic from one region to another, forming principal avenues of communication for traffic movement, with major abutting traffic generators	Mixed vehicle and pedestrian traffic High vehicle volume High pedestrian volume Moderate to high vehicle speeds Stationary vehicles alongside the carriageway Through and local traffic High traffic generation from abutting properties	V2
Freeways, motorways and expressways consisting of divided highways for through traffic with no access for traffic between interchanges and with grade separation at all intersections	Vehicle traffic only High to very high vehicle volume High speeds	V3
Arterial roads that predominantly carry through traffic from one region to another, forming principal avenues of communication for traffic movements	Mixed vehicle and pedestrian traffic Moderate to high vehicle volume High pedestrian volume Moderate to low vehicle speeds Stationary vehicles alongside the carriageway Through and local traffic Moderate traffic generation from abutting properties	V3
Sub-arterial or principal roads which connect arterial or main roads to areas of development within a region, or which carry traffic directly from one part of a region to another part	Mixed vehicle and pedestrian traffic Moderate traffic volume Low pedestrian volume Moderate to low vehicle speeds Low traffic generation from abutting properties	V4 or V5

Each Category V Lighting subcategory has its own technical parameters, outlined in AS/NZS 1158.1.1 which are required to be met for the street lighting design to comply with Australian Standards. The technical parameters include:

- Average carriageway luminance
- Point horizontal illuminace
- Upward waste light ratio

A road lighting scheme for converging and diverging traffic streams is to done in accordance to Clause 3.2.2.5:

"(a) *Converging traffic streams:*

i. *On the carriageway the whole of the converging carriageway from 10 m before the point at which the median ends to where the convergence is completed. It also includes a 3 m wide strip of the through carriageway which is contiguous with the section of the converging carriageway described above.*

ii. *On the surrounds that portion of the surrounds within 3 m of the converging carriageway, abutting the area described in Item (i). It also includes the applicable portions of any medians or islands that fall within the area described in Item (i).*

(b) Diverging traffic streams:

i. *Divergence area the location where the lanes start to diverge shall be treated as a change of carriageway width and shall be lit as specified in Clause 3.2.2.3(b).*

ii. *Gore area*

   A. *On the carriageway the area of the diverging carriageway, from 10 m before to 10 m after the nose of the raised separator island. It also includes a 3 m wide strip of the through carriageway contiguous with the section of the diverging carriageway described above.*

   B. *On the surrounds That portion of the surrounds within 3 m of the diverging carriageway, abutting the area described in Item (A). It also includes the applicable portion of any medians or islands that fall within the area described in Item (A).*

Clause 3.2.2.3(b) Diverging traffic lanes where there is an increase in the number of lanes on a carriageway, a specific illuminance design as in Clause 3.2.2.3(a) is not required, but a luminaire of the type used in the design shall be placed within 5m of the point where the lanes start to diverge." (AS/NZS 1158.1.1 2005, p20)

Hence lighting designs on exit ramps of highways should be in accordance to Figure 1 with an additional light pole placed within five meters of the start of the diverge/exit lane. Entry ramps on to highways can be designed solely in accordance to Clause 3.2.2.5(a).

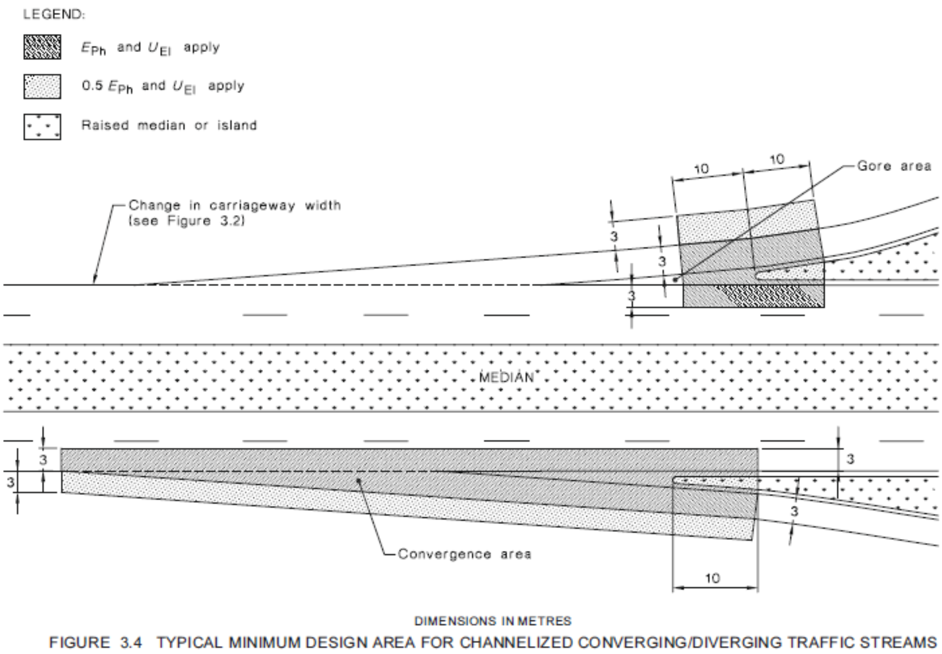

Figure 1: AS/NZS 1158.1 Typical Lighting Design Area for Diverge and Converging Locations

The previous version of Australian Standards 1158.1.1 1997 had the following standards for lighting freeway interchanges. For Urban freeways the lighting warrants AS/NZS (1997), Section 4.6.3 stated:

"Full lighting of interchanges (i.e. lighting of ramps, intersections, crossroads and main carriageways through the interchange only) is warranted where one or more of the following conditions exist:" (AS/NZS 1997, p22)

(i) *"If the total AADT (existing or estimated) on the ramps is greater than 10 000 vpd.*

(ii) *If connecting roads are provided with Category V lighting, which might adversely affect the visibility of drivers using the interchange.*

(iii) *If warrants for continuous lighting are satisfied."*

"Partial lighting of interchanges (i.e. lighting of the entry and exit gore areas plus ramps, intersections and crossroads where justified) is warranted where one or more of the following conditions exist:" (AS/NZS 1997, p22)

(i) *"If the current AADT on the freeway is greater than 25 000 vpd.*

(ii) *If the total AADT on the ramps (i.e. the sum of the volumes entering and leaving the freeway at the interchange) is greater than 5000 vpd.*

(iii) *If the road design standards are significantly below those of the approaches.*

(iv) *If a significant night-time accident record exists, which is likely to be corrected by lighting.*

(v) *If connecting roads are provided with Category V lighting, which might adversely affect the visibility of drivers using the interchange."*

For Rural freeways the lighting warrants AS/NZS (1997), Section 4.6.4 stated:

"In general, rural freeways need not be lit either continuously or at interchanges. The following exceptions may apply" (AS/NZS 1997. p23)

(a) *"Where there are unusual conditions such as a location with a high night-time accident record likely to be corrected by lighting.*

(b) *A high volume interchange exists with reduced road geometric standards.*

(c) *At a location where the background of illumination in the vicinity of the freeway is likely to adversely affect the visibility of motorists if lighting is not provided."*

According to AS/NZS (1997), it was generally accepted that lighting freeways of high traffic volumes would still have the added benefits of lighting urban areas even though the factors contributing to night accidents such as pedestrians and driveways are absent. Section 4.6.2 of AS/NZS 1158.1.3:1997 lists the following order of precedence for lighting freeway interchanges:

a) *"Ramp intersections, including the service road between these intersections where closely spaced ramps are involved.*

b) *Exit ramp gore areas.*

c) *At entry ramp gore areas.*

d) *Along ramps, particularly where substandard alignment is involved.*

e) *At converge, diverge and weaving areas on the freeway." (AS/NZS 1997, p24)*

AS/NZS 1158, 1997 and AS/NZS 1158, 2010 has seen a removal of specific warrants for freeway interchange lighting to instead giving users warrants for category of lighting and preferred layout for particular situations as example diverge and merge areas but is leaving the warrants to the individual road authority as stated in AS/NZS 1158.1.2 section 4.

"Generally the road controlling authority will be the owner/operator of the road that lighting is installed on. The responsibility of defining which road elements require lighting falls upon this body. While designers can offer advice on the level of lighting that may be required for Category V road lighting schemes as set out in AS/NZS 1158.1.1, Table 2.2, the warrants are set by the road authority" (AS/NZS 1158.1.2, p19)

2.1.1 New South Wales

Roads and Maritime Services (RMS) have adopted Austroads guidelines since 2009, with RMS supplements produced to address specific design, operation and road safety issues in New South Wales. The RMS supplements take precedence if there is a clash in standards. Austroads Guide to Road Design Part 4C: Interchanges address lighting of interchanges in section 15.3 where it states:

"The lighting of freeways, major roads and interchanges on those roads is a matter for jurisdictional policy and guidelines. Some guidance is provided in the Guide to Road Design – Part 6B: Roadside Environment (Austroads 2009g). Where it is decided to light an interchange, lighting should be provided in accordance with AS/NZS 1158." (Austroads 2009, p82)

Roads and Traffic Authority (RTA), now RMS, previously used the RTA Works Policy Manual, which is now superseded. The Works Policy Manual states that the RTA's policy was to light freeways and controlled access roads where it could be shown that positive benefits would be derived from the expenditure.

The Works Policy Manual warrants for lighting on freeway interchanges are outlined in section 2.6.5.1 of the Works Policy Manual and are as:

Policy - *" As a general policy, lighting of interchanges on freeways and controlled access roads is not to be undertaken unless a clear warrant is established."*

Location of lights – Divided into 5 zones

- *"Zone 1: Lights illuminating the junction of the ramp and the cross road*
- *Zone 2: Lights at the junction of the unloading ramp and the freeway*
- *Zone 3: Lights at the junction of the loading ramp and the freeway*
- *Zone 4: Lights for the middle section of a ramp*
- *Zone 5: Lights along the freeway between the unloading and loading ramps." (RTA 1992, p113)*

Warrants for lights at interchanges: – Cross Road is lit. The interchange should be lit under the following warrants:

- Zone 1 Always.
- Zone 2 AADT > 5,000.
- Zone 3 AADT > 10,000.

Note: The location at which the AADT is applied is not defined but it is assumed that the AADT in this situation is for vehicles on the ramp itself.

The Works Policy Manual continues to state: *Where lighting is warranted at Zone 1 and at either Zone 2 or Zone 3, and the length of the ramp is less than about 250 m, then lights are to be provided at Zone 4.*

Otherwise, lighting in Zone 4 or Zone 5 is to be provided only in exceptional circumstances and must be supported by a recommendation justifying the provision of lighting at these positions.

Similarly, if the warrant for lights in Zone 2 or Zone 3 cannot be met on traffic figures alone, a recommendation may be made based on adverse geometrics, unusual conditions, or where a significant night time accident record might be corrected by lighting." (RTA 1992, p113)

Warrants for lights at interchanges: – Cross Road is unlit.

"The interchange should not be lit unless there are unusual conditions. Before submitting any proposals for street lighting, attempts should be made to correct problem areas by alternatives, such as reviewing the reflective delineation and signposting layout. If problems still persist then the recommendation must document the options considered or tried. The provision of lighting in Zones 4 and 5 will only be approved under exceptional circumstances." (RTA 1992, p113)

By New South Wales Roads and Maritime Services adopting AS/NZS 1158, similar zones/locations are direct to be lit but AS/NZS does not include clauses invoking multiple areas of interchange ramps to be lit due one particular zone/location being lit.

2.1.2 Queensland

Department of Main Roads "Road Planning and Design Manual 2nd edition Volume 6 – Lighting" is not complete and refers uses to "Road Planning and Design Manual 1st edition Volume 17 – Lighting".

For lighting of Rural motorway interchanges Department of Main Roads adopt AS1158.1.1 as a minimum lighting treatment, with the provision for additional lighting warranted if there is an unusually high night-time accident rate, reduced geometric standards with high traffic volumes or at a location where the background of illumination in the vicinity of the motorway is likely to adversely affect the visibility of motorists if lighting is not provided.

In Urban areas Department of Main Roads adopts the following guidelines for interchange lighting:

"Full lighting of interchanges is warranted where one or more of the following conditions exist:

(i) If the total AADT on the ramps is greater than 10,000 vpd.

(ii) If connecting roads are provided with Category V lighting, which might adversely affect the visibility of drivers using the interchange.

(iii) If warrants for continuous lighting are satisfied.

Partial lighting of interchanges is warranted where one or more of the following conditions exist:

(i) If the current AADT on the motorway is greater than 25,000 vpd.

(ii) If the total AADT on the ramps is greater than 5,000 vpd.

(iii) If the road design standards are significantly below those of the approaches.

(iv) If a significant night-time accident record exists, which is likely to be corrected by lighting.

(v) If connecting roads are provided with Category V lighting, which might adversely affect the visibility of drivers using the interchange."

2.1.3 South Australia

Department for Planning, Transport and Infrastructure advocate the compliance with the Australian Standards 1158.1.1, as stated in document LD001 "The design of road lighting" with no over writing documents.

2.1.4 Victoria

VicRoads adopted the Austroads Guide to Road Design on 1 July 2012, a supplement was also developed by VicRoads to provide additional information specific to roads in Victoria. VicRoads supplement to the Austroads Guide to Road Design Part 4C – Interchanges in chapter 15.3 refers to VicRoads Traffic Engineering Manual (TEM) Volume 1, Chapter 6 – Lighting of Roads and VicRoads Guideline for Road Lighting Design for VicRoads for policy on freeway lighting requirements.

VicRoads (2013), Traffic Engineering Manual Vol 1, Chapter 6 – Edition 4, Revision 1 May 2013 states in relation to lighting of freeway interchanges that:

The intersection of the ramp with the cross road is to be lit if:

1. There is continuous lighting on the cross road.

2. The intersection is controlled by traffic signal or a roundabout.

3. The intersection is controlled by Stop or Give Way signs and there is complex geometry, high ramp traffic volumes, restricted sight lines or significant night time crash record.

VicRoads policy states that if a ramp intersection is fully lit, at least three spans of lighting along the ramp approaching the ramp intersection must be provided.

Interchange ramp diverge and merge areas are to be lit if:

- On urban freeways the exit ramps diverge and entry ramp merge areas are to be lit in accordance with the Guidelines for Road Lighting Design.
- On rural freeways the exit ramps diverge and entry ramp merge areas are not lit.
- Any resultant gap in ramp lighting less than 300 metres is to be lit.
- Freeway to freeway ramps in urban areas are to be lit.

In essence for an urban freeway if lighting is required at the intersection of the ramp and the cross road then continuous lighting of the interchange ramp is common practice.

2.1.5 Western Australia

Main Roads Western Australia (Main Roads) adopted the Austroads Guide to Road Design with a supplement developed by Main Roads to reflect the preferred practice of roads in Western Australia. Main Roads supplement to the Austroads Guide to Road Design Part 4C – Interchanges in chapter 15.3 refers to Lighting Design Guideline for Roadway and Public Spaces for the design standard for interchange lighting requirements.

The document does not specify any design requirements for interchange lighting requirements and refers to AS/NZS 1158.1.1 for calculations of applicable light technical parameters and design methods. The provision for lighting on all Main Roads freeways with high volume is further encouraged in the Main Roads Road Lighting Policy Statement Part B which states, *"The category of lighting on freeways and freeway ramps shall be that recommended for freeways in AS/NZS 1158 Part 1.1 (2005) - Table 2.1, namely V3." (Main Roads Western Australia)*

2.1.6 Australian Capital Territory

The Territory and Municipal Services advocate the compliance with Austroads Guide and the Australian Standards with no over writing documents.

2.1.7 Northern Territory

The Northern Territory transport group advocate the compliance with Austroads Guide and the Australian Standards with no over writing documents.

2.1.8 Tasmania

The Department of Infrastructure, Energy & Resources advocate the compliance with Austroads Guide and the Australian Standards with no over writing documents.

2.2 STANDARDS IN THE UNITED STATES

Minnesota uses Mn/Dot Roadway Lighting Design Manual to define warrants for lighting requirements on interchanges. Mn/Dot (2010) defines Complete Interchange Lighting (CIL) as *"applying lighting to the interchange to achieve illumination of all roadways in the interchange"*. Mn/Dot (2010) provides four warrants for Complete Interchange Lighting:

"Case CIL-1 - Complete Interchange Lighting is considered to be warranted where the total current ADT ramp traffic entering and leaving the freeway within the interchange areas exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.

Case CIL-2 - Complete Interchange Lighting is considered to be warranted where the current ADT on the crossroad exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.

Case CIL-3 - Complete Interchange Lighting is considered to be warranted where existing substantial commercial or industrial development that is lighted during hours of darkness is located in the immediate vicinity of the interchange, or where the crossroad approach legs are lighted for 0.5 miles or more on each side of the interchange.

Case CIL-4 - Complete Interchange Lighting is considered to be warranted where the ratio of night to day crash rate within the interchange area is at least 1.5 times the state-wide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate." (Mn/DOT 2010, p1-7)

Mn/Dot (2010) defines Partial Interchange Lighting (PIL) as *"the illumination of only the parts of the interchange that are the most critical to the night driver, which are the merge-diverge areas of the ramp connections, intersections and other critical roadway features"*. The warrants for Partial Interchange Lighting are:

"Case PIL-1 - Partial interchange lighting is considered to be warranted where the total current ADT ramp traffic entering and leaving the freeway within the interchange areas exceeds 5,000 for urban conditions, 3,000 for suburban conditions, or 1,000 for rural conditions.

Case PIL-2 - Partial interchange lighting is considered to be warranted where the current ADT on the freeway through traffic lanes exceeds 25,000 for urban conditions, 20,000 for suburban conditions, or 10,000 for rural conditions.

Case PIL-3 - Partial interchange lighting is considered to be warranted where the ratio of night to day crash rate within the interchange area is at least 1.25 times the state-wide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in the night crash rate."(Mn/DOT 2010, p1-8)

The American Association of State Highway and Transportation Officials (AASHTO) contain the most widely used warrants for lighting in the USA. AASHTO is very similar to the Mn/Dot Roadway Lighting Design Manual as adopted by the state of Minnesota.

AASHTO has three freeway lighting standards, Continuous lighting, Complete Interchange Lighting and Partial Interchange Lighting. The definition and warrants for Complete and Partial Interchange Lighting as stated in AASHTO (2005) is:

"Complete Interchange is defined as "a lighting system that provides relative uniform lighting within the limits of the interchange, including:

- *Main lanes*
- *Direct connection*
- *Ramp terminals*
- *Frontage road or cross road intersections*

The warrants provided are:

CIL-1 – Where the total current ADT ramp traffic entering and leaving the freeway within the interchange area exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.

CIL-2 – Where the current ADT on crossroad exceeds 10,000 for urban conditions, 8,000 for suburban conditions, or 5,000 for rural conditions.

CIL-3 - Where existing substantial commercial or industrial development that is lighted during hours of darkness is located in the immediate vicinity of the interchange, or where the crossroad approach legs are lighted for 0.5 mile or more on each side of the interchange.

CIL-4 – Where the ratio of night to day crash rate within the interchange area is at least 1.5 times the state-wide average for all unlighted similar section, and a study indicates that lighting may be expected to result in a significant reduction in night crash rate.

Where crash data are not available, rate comparison may be used as a general guideline for crash severity.

Partial Interchange Lighting is defined as "a lighting system that provides illumination only of decision making areas of roadways including:

- *Acceleration and deceleration lanes*
- *Ramp terminals*
- *Crossroads at frontage road or ramp intersections*
- *Other areas of night time hazard.*

The warrants provided are:

PIL-1 – Where the total current ADT ramp traffic entering and leaving the freeway within the interchange exceeds 5,000 for urban conditions, 3,000 for suburban conditions, or 1,000 for rural conditions.

PIL-2 – Where the current ADT on freeway through traffic lanes exceeds 25,000 for urban conditions, 20,000 for suburban conditions or 10,000 for rural conditions.

PIL-3 - Where the ratio of night to day crash rate within the interchange area is at least 1.25 times the state-wide average for all unlighted similar section, and a study indicates that lighting may be expected to result in a significant reduction in night crash rate.

Where crash data are not available, rate comparison may be used as a general guideline for crash severity."

Both American standards AASHTO and Mn/Dot Roadway Lighting Design Manual use the same warrants to determine if an urban and rural freeway interchange should be completely or partially lit. Traffic volumes are the major warrants determining the level of street lighting required, similar to the approach used by the Department of Main Roads in Queensland, Australia, which was an approach originally adopted by New South Wales under the RTA Works Policy Manual before adopting Austroads that in turn refers users to AS/NZS 1158.1.1.

2.3 STANDARDS IN UNITED KINGDOM AND EUROPE

The United Kingdom and Europe are somewhat dissimilar to those in Australia and the United States as they do not have specific requirements for lighting of grade separated interchanges particularly diverge and merge areas. Instead they focus on the warrants for continuous lighting of the main carriageways based on traffic volumes and the spacing between interchanges.

British Standard 5489-1:2003 *Code of Practice for the design of road lighting* has been revised to incorporate European Standard 13201-2 which has been approved by the European Committee of Standardization (CEN) and must adopted by CEN members.

According to BS 5489-1:2003 and TD 34/07 grade separated interchanges are treated as main carriageways, with the provision of lighting determined by the traffic flow (ADT).

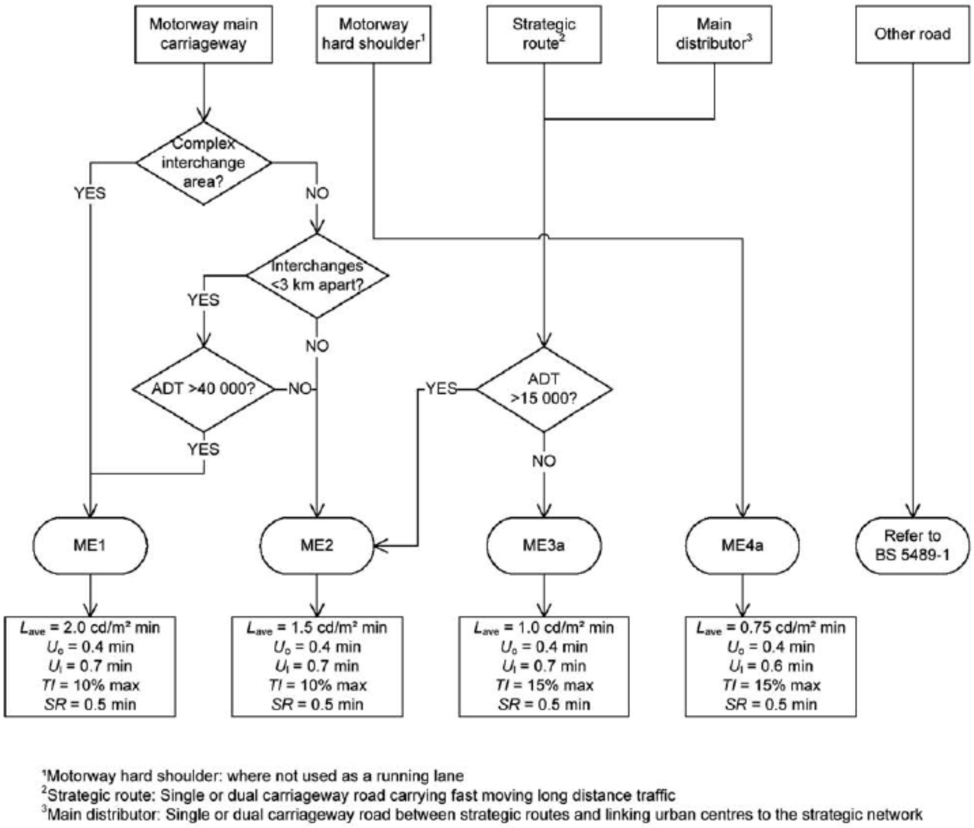

Figure 2: TD34/70 Lighting Design Criteria for Road Network

Figure 2 is developed from Table 1a of EN 13201-2 and Table B.2 of BS 5489-1. It is a clear illustration showing that the provision of lighting is directly related to traffic flow.

Conflict areas such as free flow link roads connecting motorways have a different lighting class, CE lighting which is to be in conjunction with motorway lighting (ME).

Table 2: BS5489-1:2003 Lighting classes for conflict areas

Traffic route lighting class	Conflict area lighting class
ME1	CE0
ME2	CE1
ME3	CE2
ME4	CE3
ME5	CE4

Previously the British standard stated, *"Free flow link roads connecting motorways may be lit to the same standard as the main carriageway of the motorways they are connecting. Motorway slip roads may be lit to one class lower than the main carriageway" (BS 5489-1 2003, p38)*. Changing this standard reduces the required luminance and overall reduces the energy output and hence the running cost, however the installation and maintenance cost still remain the same.

2.4 INTERCHANGE RAMP ACCIDENT HISTORY

The following research looks into the crash characteristics and types of crashes that commonly occur on interchange entry and exit ramps. Previous studies have found that the most common crash type is rear end collisions for merge manoeuvres and that exit ramps have a higher rate of crashes compared to entry ramps.

Anne T. McCartt (2003) looked at 33 interchanges containing 176 ramps in North Virginia and analysed 1150 crashes. Two-thirds of the crashes occurred on ramps with 49% occurring when at-fault drivers were exiting the main roadway with 36% occurring on entry ramps. 48% of crashes on the ramps were of the run-off type, with accidents on exit ramps making up 53% and 37% on entry ramps, it was also more common for these types of accidents to occur in inclement weather and at night. The most common type of accident on entry ramps were rear-end collisions (48%). Run-off type crashes are described as vehicles leaving or straying off the travel lane(s) and striking an off-road object or overturning off the road.

Janoff, M.S (1982) cited a study by Lundy which analysed the accident rates for 10 years on interchanges in California with an average accident rate (accident rate is per 1 million vehicle per miles) of 0.95 on exit ramps and 0.59 on entry ramps indicating that accident rates at on ramps are consistently lower than those at off ramps.

Previous studies indicated ramp traffic volume as a key variable effecting ramp accident. Khorashadi (1998) found that 15% of accidents on California state highways occurred on ramps. Total accidents occurring between 1992-94 on California State Urban highway ramps was 60,906 with 64% occurring on exit ramps. The results also showed that the severity of the accident on both the entry and exit ramps were similar as shown in Table 3.

This supports the claim that exit ramps are more prone to accidents than entry ramps as documented in previous research papers.

Table 3: Khorashadi (1998) Urban highway ramp accident severity

Accident Type	Off-Ramp (Ratio)	On-Ramp (Ratio)
Fatal	167 (0.4%)	91 (0.4%)
Injury	15115 (38.8%)	7948 (36.2%)
Property Damage Only (PDO)	23654 (60.8%)	13931 (63.4%)
Total	38936	21970

Khorashadi (1998) included the average accident frequency on exit and entry ramps during dark light conditions, with an accident on exit ramps occurring on average of twice compared to entry ramps during dark conditions.

Janusz and Hauer (1995) conducted a study on police reported ramp related crashes between 1982 and 1992 on two Toronto urban freeways, categorising the crashes into three categories, begin-ramp, mid-ramp, and end-ramp. 2368 accidents were reported with 585 accidents occurring at the entry ramp merge point, 216 accidents at exit ramp diverge points, 862 mid-ramp and the remaining 705 accidents occurring at the ramps interaction with the adjoining minor road or intersection. The results show that 70% of the accidents on ramps are from vehicles entering or leaving an interchange ramp, with 40% being rear-end collisions. This raises the question, if street lighting is provided will this reduced rear-end collisions? One would think not, as typically these types of accidents occur due to drivers not focusing on the vehicle in front of them instead of focusing on vehicles they are trying to merge or diverge with.

Styles and Luk (2006) refer to an on going program of campaigns aimed at improving lane discipline, particularly merging, conducted by RoadSafe Auckland and Transit New Zealand. According to the article, the merge area crash rate is more than double the crash rate between interchanges with the most common crashes related to poor lane discipline, including poor merging, lack of indication and following too closely. If vehicles merge correctly it allows other motorists to adjust and maintain traffic flow, poor merging creates problems for other vehicles, resulting in secondary incidents involving motorists in adjacent lanes.

2.5 RESEARCH IN TYPICAL LIGHTING INSTALLATIONS

Research was done to find previous research papers and journal articles relating to different levels of lighting provided on grade separated interchange ramps to facilitate a method for measuring the data collected in the study of the Sydney to Newcastle motorway (M1) study. Three categories for the levels of lighting provided on grade separated interchange ramps were used:

1. Complete lighting
2. Partial lighting
3. Zero lighting

2.5.1 Complete Lighting of Grade Separated Interchange Ramps

Complete lighting is defined as full lighting provided from the start of the entry/exit ramp to the intersection with the connecting roadway. Figure 3 illustrates an exit ramp with complete interchange lighting (CIL).

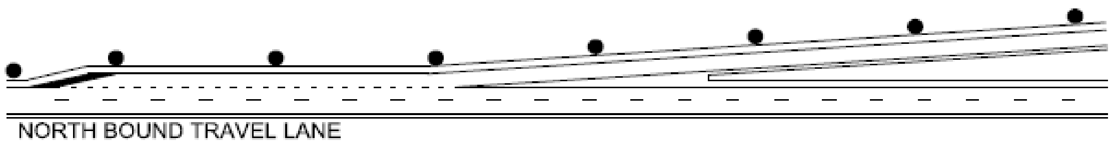

Figure 3: Complete Interchange Lighting - Exit ramp

Research by Janoff (1982) did not record accident rates on interchange ramps but instead compared the traffic operating environment on entry and exit ramps, which gave and insight into driver behaviour when encountering a completely lit and partially lit interchange ramps and interchange ramps with no lighting. The study consisted of vehicle observations on a selected interchange were the lighting configuration was controlled. The study of the completely lit interchange observed 141 vehicles using the exit ramp and 149 vehicles using the entry ramp. The recorded data showed that the driver's frequency of brake light activation and use of high-beam lights was reduced on completely lit ramps compared to the recorded data on partial lit ramps.

The data indicates that by providing a completely lit entry and exit ramp a better traffic-operating environment is created for drivers, this will be analysed in section 4 to determine if accident crash records for the M1 study support this idea. Janoff (1982) research states;

"A major objective of this research was to develop specific (i.e., quantitative) recommendations regarding the effectiveness of Complete Interchange Lighting (CIL) and Partial Interchange Lighting (PIL), such recommendations are difficult to make without adequate accident data related to CIL and PIL."

The intention of this dissertation is to determine if accident data can provide insight into the safety performance of CIL and PIL.

2.5.2 Partial Lighting of Grade Separated Interchange Ramps

During the study of partial interchange lighting conducted by Janoff (1982), two PIL layouts were used as shown in Figure 4. During the study, 279 vehicles on the exit ramp and 286 vehicles using the entry ramp were observed, The results showed that there was no difference in driver behaviour regarding average velocity, average acceleration and shoulder encroachments when lighting was reduced to partial conditions, however a significant result was that drivers diverged and merged later under partial lit conditions compared to completely lit conditions.

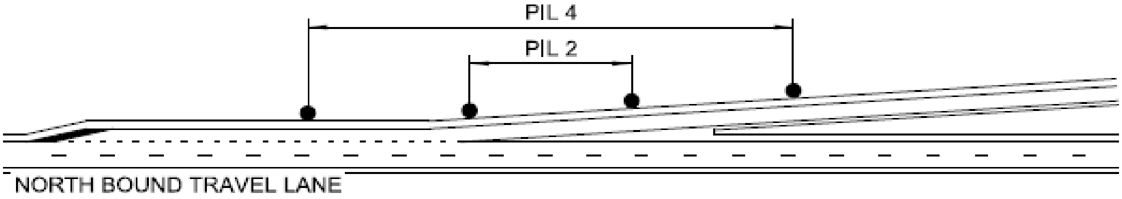

Figure 4: Janoff (1982) study - Partial Interchange lighting layout

This indicates that by only providing lighting at the gore area and not at the start of the deceleration lane and at the end of the acceleration lane drivers are not utilising the full length of deceleration and acceleration lane provided.

Interestingly a mail out survey to all states in the US and Canada by Janoff (1982) to discover the practiced layout of lighting at grade separated interchanges, discovered that of the 39 PIL systems reported, 74% place light poles at both the exit and entry ramp. The most common locations for a light pole at an exit ramp area is in the gore area and near the beginning of the deceleration lane. On an entrance ramp the light pole is commonly placed near the end of the acceleration lane. The treatment of PIL for exit ramps commonly used in the US and Canada coincides with the treatment recommended in AS/NZS 1158.1.1 as document in part 2.1 of this report and suggest that most agencies prefer to light the exit ramp over the entry ramp.

Monsere and Fischer (2008) conducted a study of 30 interchanges where full interchange lighting was reduced to partial interchange lighting. Using a calibrated model the results are show in Table 4.

Table 4: Monsere and Fischer (2008) Lighting reduction results

Crashes	Observed	Calibrated Model	Percentage Change
Total day crashes	1991	2026.94	-1.73
Injury day crashes	833	914.74	-8.85
Total night crashes	828	808.82	+2.46
Injury night crashes	335	381.98	-12.16

The observed traffic volumes during the day are significantly higher than the volumes during the night which influenced the results in showing less crashes during the night. However the fact that there is a 2.46% reduction in the number of accidents occurring when changing from full interchange lighting to partial interchange lighting indicates that partial lighting should be adopted as indicated in AS/NZS 1158.1.1. The extra installation cost, maintenance cost and introduction of more road side hazards in the form of light poles, required to achieve CIL appear to have little affect on the reduction in night time accidents on grade separated interchange ramps.

In contrast to Monsere and Fischer (2008), Griffith (1994) conducted a comparison of the safety of lighting options on urban freeways with the study area being Minnesota. The interchanges with lighting were classified as partial intersection lighting according to Mn/Dot (2010). The total day accident rate was 0.48 compared to a night accident rate of 0.70 (accident rate is per 1 million vehicle per miles) giving a 45.8% increase in accident rates.

2.5.3 Zero Lighting of Grade Separated Interchange Ramps

CIE (1992) cited a before and after study which was conducted on freeway interchanges across 30 States of America by Gramza (1980). Before lighting was installed 83 accidents occurred during day light with 76 accidents at night, after street lighting was installed at the 30 interchanges 80 accidents were recorded during the day and 43 at night. By installing street lighting at freeway interchanges the results showed a 43% reduction in night time accidents. Whilst the study has found a significant reduction in night time accidents on freeway interchanges when street lighting is installed the study does not explain were the lights were installed and what accidents were occurring before the installation of street lighting and the accidents occurring after the installation of street lighting, the accidents could have been reduced at the adjoining intersection and not the merge and diverge area, as is the focus of this research paper.

2.6 SAFETY BENEFITS OF ROAD LIGHTING

There have been numerous studies on the safety benefits and effects of road lighting on motorways, but very little research has been conducted on interchanges and if there is any added safety benefit of street lighting on entry and exit ramps.

CIE (1992) concludes that road lighting, when properly designed, installed and maintained reduces night-time accidents by between 13 and 75 per cent. This range is derived from an analysis of 62 lighting and accident studies produced in 15 countries. 85% of these studies showed that lighting was beneficial with about one third of these having statistical significance.

The conclusions of CIE (1992) suggest that of the 62 safety related lighting, studies they analysed, only 28% showed a statistical significance of lighting being beneficial to accident reduction. Only 3 of the 62 studies concentrated in the lighting of interchanges. Two of the three studies were conducted Gramza (1980), a before and after analysis of 30 interchanges with street lighting and a more detailed stepwise regression test on 116 freeway interchanges on nine independent variables. The results from both studies showed a benefit in the installation of street lighting, however the detailed study found that *"neither illumination nor number of lights was found to have a significant influence on total accident rates when other selected factors were considered" (CIE 1992)* this indicates that street lighting alone may not reduce accidents if other factors like road geometry and weather conditions are influencing driver behaviour. The study did indicate that *"when distinctions are made in the types and severity of accidents, and types and locations and number of lights were found to significantly influence the accident rates" (CIE 1992)*, for the results on the before and after analysis see section 2.5.3.

A study on Dutch motorways by Wanvik (2009) concluded that lighting on motorways reduced night time accidents by 49%, but the effect is significantly smaller during rainy conditions with a 32% reduction. Wanvik (2009) stated that Bruneau et al (2001) has completed the most comprehensive study of the effects of roadway lighting on motorways, with 22, 740 accidents across 770km of motorways in Qubec. The study found a 33%

reduction in night time accidents if continuous lighting was used and a reduction of 49% if junction lighting only was used both being compared to an unlit motorway. This finding suggests that providing less lighting (junction lighting) better results are achieved i.e. ‘less is more’.

Donnell (2009) concluded that lighted intersections and interchanges tend to have fewer crashes than unlighted intersections/ interchanges. However there appears to be no major benefit of complete interchange lighting compared to partial lighting at interchanges along urban, suburban or rural freeways, as evidence is mixed for some locations. The findings from Monsere and Fischer (2008) outlined in section 2.5.2 support Donnell (2009) conclusion.

The research has shown that there is a safety benefit in providing street lighting, but can this be adopted for interchange entry and exit ramps? Or do accidents occur at these locations regardless of providing daylight conditions at night?

Current practice is that good street lighting causes a 30% reduction in night time road casualties compared with poor or no street lighting. Crabb (2009) implied that in the majority of the study cases, the crashes at night reflected day time trends regardless of lighting being installed, hence questioning the benefits provided by street lighting and subsequently the 30% reduction value used in safety benefit cost analysis. Crabb (2009) used crash data from 2001 to 2005 on the whole road network in Great Britain to draw comparisons to accidents occurring during the day and night and if street lighting was present. The recorded data showed 771,216 accidents occurred during daylight with 299,723 occurring in darkness, the presence of street lighting at the sites of the accidents in darkness are recorded in Table 5 below:

Table 5: Crabb (2009) - Street lighting presence in recorded accidents in darkness

Lighting Condition	Lighting Presence	Accidents 2001-05
Darkness	Street lights present	229,967
	No street lighting	61,397
	Street lighting unknown	8,359

In the five year study period 21% of accidents occurred in darkness where street lighting was present, while less than 6% of accidents occurred where street lighting was not installed. These results suggest that lighting does not play a significant role in the reduction of night time accidents. Crabb (2009) concluded that overall accidents at night whether street lighting is present or not are more serve than in the day time, suggesting this could be due to a number of factors such as lower traffic volumes allowing higher speeds. Street lighting was found to have a large effect on reducing the number of accidents involving vulnerable road users i.e. pedestrians and cyclists. Therefore is there any added safety benefit of lighting freeway interchange ramps as pedestrians and cyclists are generally absent from freeways.

Performance studies on the British freeway network have shown that using there current standard of completely lighting entry and exit ramps that there has been a 30% reduction in accidents compared to no lighting.

According to Elvik (1994) the best current estimate regards to safety effects of road lighting is a 65% reduction in night-time injury accidents and a 15% reduction in night-time property damage only accidents.

To determine the Benefit Cost Ratio (BCR) for a treatment to reduce accidents on NSW roads, RMS have a BCR excel spread sheet that enables users to determine the most cost effective solution to reduce accidents that occur regularly on a particular section of road. Table 6 captures a section of the RMS BCR spread sheet, showing the accident reduction in a percentage for the installation of street lighting as the treatment for accident reduction. The crash descriptions have been selected on the basis of the general crash types occurring on diverge and merge ramps as outlined in section 2.4 and the frequently occurring crash types on the M1 as document in section 3 and Appendix C.

Table 6: Roads and Maritime Crash Treatment Reduction Rates Matrix - BCR

RMS CRASH TREATMENT REDUCTION RATES MATRIX - BCR					
Crash Description		**Adjacent - Right Near**	**Adjacent - Other**	**Rear-End**	**Lane Change**
Speed zone		**90k or greater**	**90k or greater**	**90k or greater**	**90k or greater**
61	Install street lighting, **night time crashes only**				
62	Install intersection lighting, **night time crashes only**	20	20	20	20
63	Install lighting at pedestrian facilities, **night time crashes only**				

Treatment 61 is relevant for grade separated interchange ramps and it can be seen that for all crash types at 90km/hr or above have been greyed out indicating that there is either no cost benefit or the treatment isn't relevant for that situation. The method RMS user to determine the BCR of street lighting illustrates that there is no added safety benefit for the installation of street lighting for high speed roads unless at an intersection.

2.7 ACCIDENT COSTS

NSW Roads and Maritime Services along with Transport for New South Wales estimate accident costs using two main approaches.

1. Willingness to Pay Approach.

2. The Human Capital Approach.

The Willingness to Pay Approach uses an ex-ante measure of the amount that individuals are willing to pay for accident prevention. Values of accident costs are derived from Stated Preference surveys where respondents are asked to choose hypothetical scenarios systematically varied in safety, travel time and cost. Transport for New South Wales recommends using fatality and injury costs estimated from willingness to pay approach for economic appraisal of transport projects, programs and initiatives, policies and regulation reforms that may reduce transport accidents in future years.

When the crash type is known a detail safety analysis can be done using the accidents costs shown in Table 7, the highlighted rows indicate the accidents that are commonly associate with merge and diverge maneuvers on interchange entry and exit ramps. The crashes have been grouped by RUM (Road User Movement) Code as defined by the NSW Centre for Road Safety.

Table 7: Crash costs by crash type - Transport for NSW

Crash type group		Cost ($'000)	
RUM code	**Brief description**	**Urban**	**Rural**
Two vehicle type			
10,11 - 19	Intersection, from adjacent approaches	$61.90	$252.80
20, 50	Head-on	$176.40	$433.60
22 - 29	Opposing vehicles; turning	$62.40	$216.00
30 - 32	Rear end	$38.00	$105.80
33 - 35	Lane change	$49.20	$247.50
36 - 37	Parallel lanes; turning	$41.30	$186.90
40	U-turn	$55.60	$231.10
42, 47, 48	Vehicle leaving driveway	$44.70	$166.80
51, 52, 54	Overtaking, same direction	$62.40	$140.40
41, 60 – 63, 94	Hit parked vehicle	$60.60	$194.40
Average Two Vehicle Crash Cost		**$65.30**	**$217.50**
One Vehicle Types			
00 - 09	Pedestrian, crossing carriageway	$193.60	$517.10
64 – 66, 91	Permanent obstruction on carriageway	$100.80	$171.60
67	Hit animal	$51.60	$63.20
70, 72	Off carriageway, on straight	$81.40	$153.90
71, 73	Off carriageway, hit object	$108.60	$183.20
74	Out of control on straight	$90.10	$161.20
80, 82, 84, 86	Off carriageway, on curve	$92.00	$153.10
81, 83, 85, 87	Off carriageway, hit object	$119.80	$158.70
88	Out of control on curve	$82.80	$135.40
Average One Vehicle Crash Cost		**$102.30**	**$188.60**

Source: Based on crash cost 2001 - costs by accident type, DCA data capture Andreassen 2001. Indexd to Dec 2012 by AWE

2.8 INSTALLATION AND MAINTENANCE COSTS

There are approximately 2.28 million street lighting lamps in service in Australia, with around 33% on main roads and 67% on local roads. The annual cost of public lighting in Australia exceeds $250 million. Street lighting is the single largest source of greenhouse gas emissions from local government, typically accounting for 30 to 60 per cent of their greenhouse gas emissions.

Major road lighting, Category V lighting makes up only 27% of the 2.28 million streetlights installed nationally but represents 60% of the energy consumption. The major lighting types are mercury vapour (12% of major road lighting national numbers – down from 25% in 2002/3) and high pressure sodium (86% of national numbers – up from 75% in 2002/3). (Street light strategy, 2011)

2.8.1 Installation Costs

The installation price for streetlights seems to vary from $5500 to $16,000 depending on the project and the contractor used. Recent prices obtained for varying interchange projects around NSW are as follows;

- Pacific Highway Bonville Interchange upgrade, Mailmans track and Archville road interchange. Approximately $7200 per light to install.
- Pacific Highway Stewart Point Interchange, approximately $16,000 per light.
- Hunter expressway the figure adopted for installation was $5800 per light.

The installation cost of street lighting varies greatly depending on the following:

- If a transformer is needed to reduce the power from high voltage to low voltage.
- The availability of power at the site and the distance of conduits, trenches and cables required to supply power to the site.
- The manufacture used to supply the light poles.

With no exact price, determining the cost benefit of street lighting as standard figure is even more challenging to predict.

2.8.2 Maintenance Costs

The on-going maintenance costs for street lights, which includes energy and routine maintenance varies from $400 to $3500 depending on the location and company or council in charge of maintaining the street lights. Recent prices obtained for varying interchange projects around NSW are as follows;

Pacific Highway Bonville Intersection upgrade, yearly street lighting maintenance break down per light is;

- $300 for energy usage
- $130 for routine maintenance

The street lighting design for the grade separated Bonville Interchange ramps was designed as Complete Interchange Lighting consisting of 54 lights on the four entry and exit ramps giving an annual maintenance cost of $23,220. If the street lighting on the interchange ramps was reduced to Partial Interchange Lighting as per AS/NZS 1158.1 leaving on 19 lights on the entry and exit ramps the yearly maintenance cost would be $8170 a saving of $15,050 for the project cost and ultimately the tax payer. If PIL was adopted in the initial installation costing would have been reduced from $388, 800 to $136, 800 a saving of more than $250, 000 for the project.

M1 Sydney to Newcastle maintenance cost for street lighting is $3500 per pole; this is due to the WH&S and requirements for working within a 110km/hr road corridor, with high traffic volumes. To perform any maintenance on a street light along the M1 traffic control and lane closures are essential to perform the maintenance work in a safe environment.

The running cost for the street lighting at interchanges along the M1 are metered and cost around $0.90 to $1.00 per day, depending on the cost of electricity and how long the lights are on each day. This results in a maximum annual cost of $365 per street light.

2.9 DATA COLLECTION METHODS

Using a Roads and Maritime Services data package Crashlink. The crash history at selected grade separated interchanges along the Sydney to Newcastle motorway (M1) during both the day and night will be captured and analysed.

3. DESIGN AND METHODOLOGY

3.1 AIMS AND OBJECTIVES

The project aim is to determine the safety benefit of lighting on interchange ramps on the M1.

The objectives of the project are:

1. Review literature related to provision of street lighting on entry and exit ramps at grade separated interchanges and in particular the areas of;
    - Provision for street lighting on entry and exit ramps for grade separated interchanges within Australia and around the world.
    - Review of the Australian standards.
2. Determine specific grade separated interchange entry and exit ramps on the M1 that have similar geometry and ramp features.
3. Determine the level of lighting provided at the selected grade separated interchanges.
4. Determine the crash history and design elements of the selected sites.
5. Compare the lit versus unlit interchange ramps on safety measures.
6. Determine on a benefit cost basis whether lighting on these roads appears to be a sound investment.
7. Recommend on whether or not changes are required to existing design standards for street lighting on entry and exit ramps.

3.2 SITE SELECTION

The Sydney to Newcastle motorway, commonly known as the M1 was selected as the study area due to the fact that it has a high volume of traffic, contains 16 grade separated interchanges and has crash history dating back to 1996. The following 9 sites along the M1 have been selected for analysis;

- Site 1 – Newcastle Interchange.
- Site 2 – West Wallsend Interchange (Half Interchange).
- Site 3 – Awaba Interchange.
- Site 4 – Freemans Dr Interchange (Half Interchange).

- Site 5 – Morisset Interchange.
- Site 6 – Warnervale Interchange.
- Site 7 – Service Centre Interchange.
- Site 8 – Tuggerah Interchange.
- Site 16 – Mt Colah Interchange (Half Interchange).

Seven of the grade separated interchanges were deemed not suitable for analysis in this research as the sites had independent variables including varying horizontal and vertical geometry, rock cuttings, merge types and acceleration and deceleration lengths. The independent variables would cause potential analysis problems, as the data would not be valid for a like for like comparison. The sites excluded from the study of the M1 are;

- Site 9 – Ourimbah Interchange.
- Site 10 – Somersby Interchange.
- Site 11 – Kariong Interchange.
- Site 12 – Calga Interchange.
- Site 13 – Mount White Interchange.
- Site 14 – Brooklyn Interchange.
- Site 15 – Berowra Interchange.

The study of the M1 is considering the street lighting configurations and crash statistics on the motorway grade separated exit ramp, diverge area and entry ramp, merge area only. A diverge area illustrated in Figure 5 is the area which gives vehicles the opportunity to perform a diverging manoeuvre, generally between the start of diverge taper and the exit ramp gore.

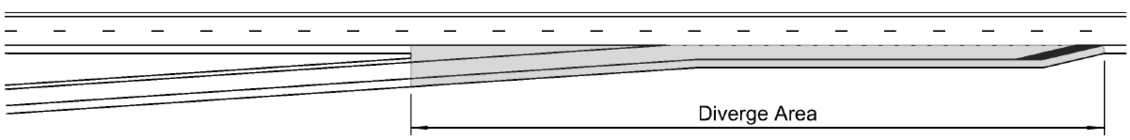

Figure 5: Grade Separated Interchange Exit Ramp Diverge Area

The length of diverge area should be 235m for an 110km/hr speed environment, as per Austroads Guide to Road Design Part 4C: Interchanges. Figure 6 is the diagram used in Austroads to determine the diverge area and deceleration distance required, with Dd determined using through road design speed and connecting roads speed. The exit lane geometry may vary depending on the interchange location.

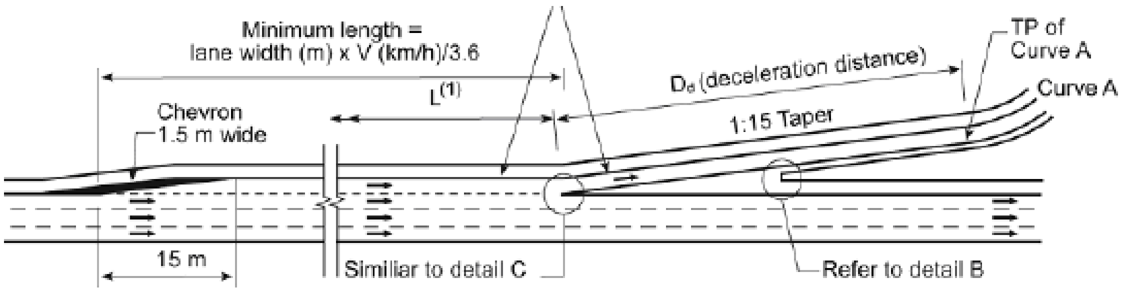

Figure 6: Austroads Part 4C: Interchanges - Single Lane Exit Ramp

The merge area illustrated in Figure 7 is the area, which gives vehicles the opportunity to perform a merging manoeuvre, generally between the end of the entry ramp gore and the end of the merge taper.

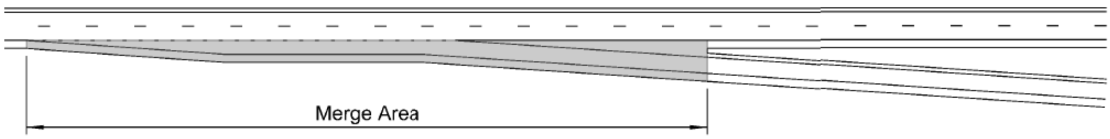

Figure 7: Grade Separated Interchange Entry Ramp Merge Area

The length of the merge area should be 385m for a 110km/hr speed environment, allowing vehicles 4 seconds of parallel travel before merging, as per Austroads Guide to Road Design Part 4C: Interchanges. Figure 8 is the diagram used in Austroads to determine the merge area required, with T being the taper based on 1.0m/sec of lateral movement and L being 4 seconds of travel time.

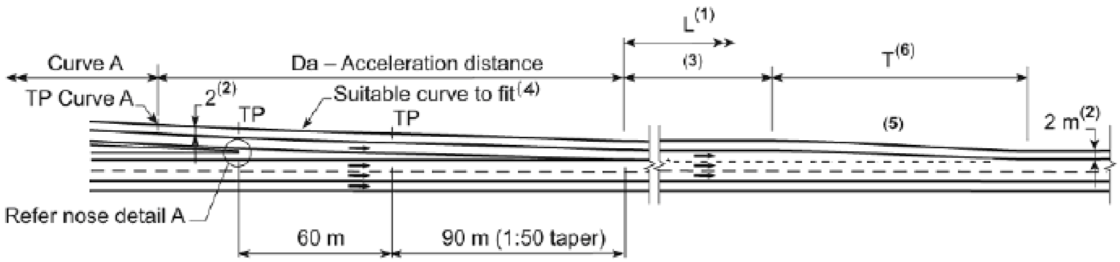

Figure 8: Austroads Part 4C: Interchanges - Single Lane Entry Ramp

The length of the merge and diverge area will be considered at each study site to determine if the lengths vary and if there is any relationship in reduced or increased merge and diverge lengths and accidents and the presence of street lighting.

3.2.1 M1 ENTRY AND EXIT RAMP LIGHTING WARRANTS

The superseded Works Policy Manual, as a general policy, requires that lighting of rural interchanges not to be undertaken, unless a clear warrant can be established as outlined in section 2.1.1.

The Australian Standard 1997 stated that *"In general, rural interchanges need not be lit"*, but goes on to detail three exceptions: accident histories, high volume with reduced geometry, background illumination refer to Section 2.1 for details. However current AS/NZS 1158 specifies Category V3 lighting for freeway interchange ramps, with the lighting design to be in accordance to AS/NZS 1158.1.1 clause 3.2.2.3 for merging traffic and 3.2.2.5 for diverging traffic.

As AS/NZS refers to road authority for the lighting road warrants, rural dual carriageway roads are generally not lit, with recent practices to either;

- Illuminate all merge/diverge areas of the intersection.
- Illuminate no merge/diverge areas of the intersection.
- Illuminate all or a proportion of the entry ramps merge areas only.

Considering the M1 Sydney to Newcastle motorway was completed in the mid 1990's, it would be assumed that all interchange lighting should be in accordance to AS/NSZ 1997 and the RTA's Works Policy Manual. The result would be that no interchange should be lit unless the crossroad is lit on each side of the freeway reserve, and then each zone would be lit according to AADT. Retro fitting of street lighting on interchange ramps could have occurred during roadwork upgrades and to address safety issues if, street lighting was deemed a possible solution at the time.

3.3 DATA COLLECTION

Using a car dashboard-recording camera called blackvue each interchange along the M1 was driven to record the level of lighting, location of lighting and number of streetlights used on each entry and exit ramp. Driving through each site recording data was the most practical and safest way of collecting data first hand. OH&S would require traffic control and speed reduction if the data was collected by pulling over at each site and walking through inspecting the lighting layout due to the high speed environment and high traffic volumes.

Crash statistics for each site were obtained through Crashlink in conjunction with Geographic information system (GIS) software. Crashlink is a database containing all reported crashes across NSW, integrated with GIS crash maps could be produced showing the location of all reported crashes. Crashlink reported 8343 crashes along the M1 between 1996 and August 2014 with 419 crashes occurring in the diverge or merge areas of the grade separated interchanges for the selected 9 sites. GIS allowed crashes for each interchange to be dissected to ensure that only the relevant crashes occurring in the vicinity of the diverge and merge areas were selected as illustrated in Figure 9, crash maps for each site are included in Appendix A.

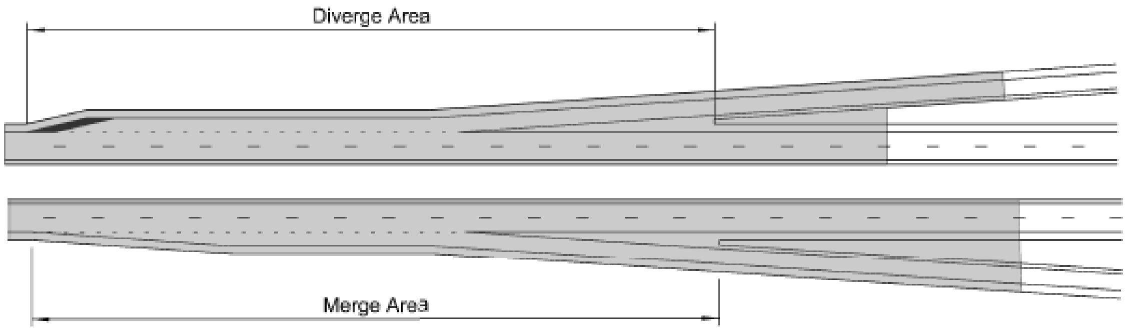

Figure 9: Diverge and merge crash location areas

To obtain the required crashes a simple procedure was followed;

1) Load general parameters in to Crashlink, to only select crashes on the M1 motorway between 1996 and 2014.

2) Load general parameter crashes (8343) crashes into GIS.

3) Using an aerial photograph to select all crashes with in diverge and merge areas for site 1.

4) Save selected crashes as a crashID

5) Using Crashlink to run the crashID for site 1 and produce a detailed crash report for the selected crashes only, with each crash allocated an ID number.

6) Using the detailed crash report from Crashlink and GIS, allocate each crash to the exit or entry ramp it occurred on using the ID number.

7) The procedure was repeated for all 9 sites. Once obtained the data could be sorted for analysis.

An accurate AADT volume for each interchange entry and exit ramp could not be obtained due to traffic counters only being allocated to specific locations along the M1. As a result this research paper will purely focus on lit and unlit exit and entry ramps, the number of crashes occurring, the types of crashes occurring and the severity of crashes occurring regardless of traffic volumes.

Of the 9 sites selected there are 15 entry and exit ramps, the number of entry and exit ramps with lighting are as follows;

- 12 entry ramps with lighting.
- 3 entry ramps with no lighting.
- 7 exit ramps with lighting.
- 8 exit ramps with no lighting.

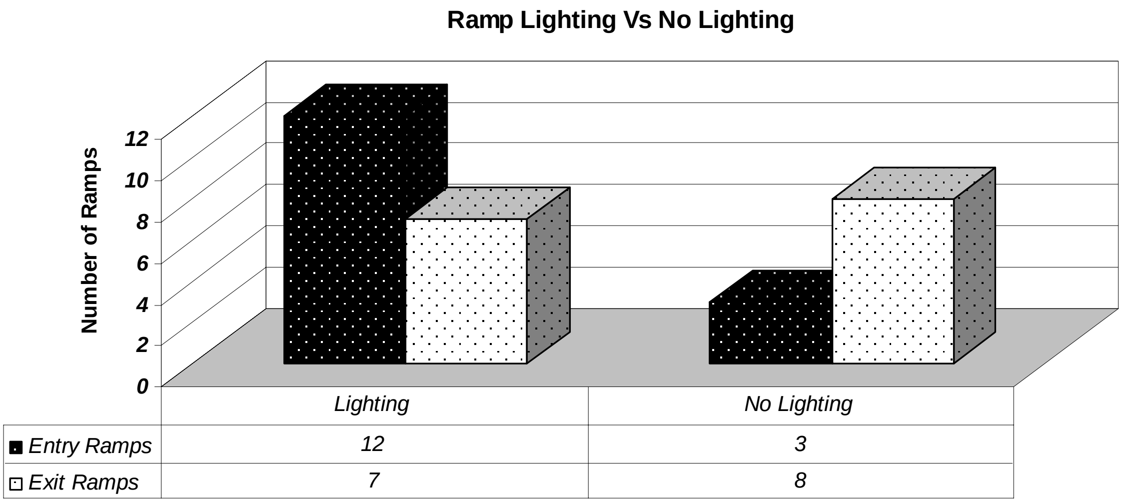

Figure 10: M1 Study - Ramp Lighting and No Lighting Breakdown

3.3.1 SITE 1 – M1 – NEWCASTLE INTERCHANGE

Site 1 Newcastle Interchange is a full service interchange consisting of 4 ramps, 2 north facing ramps and 2 south facing ramps. The exit ramps are 35m below the standard of 235m, whilst the entry ramps fail to meet Austroads standards of 385m for an 110km/hr zone as previously outlined. The horizontal and vertical geometry at the interchange is sound with clear visibility to approaching exit ramps and sufficient site on entry ramps. All four ramps on the Newcastle interchange are completely lit with the northbound ramps consisting of 6 lights whilst the southbound entry ramp has 7 lights and the southbound exit ramp consisting of 5 lights. The total number of crashes occurring at the Newcastle interchange is 45, with 49% occurring during darkness, dawn or dusk. Figure 11 is a schematic layout of the Newcastle interchange illustrating the approximate location and number of streetlights on each entry and exit ramp. Table 8 is a summary of the lighting conditions and number of crashes occurring on each ramp. The full detailed crash report is shown in Appendix C.

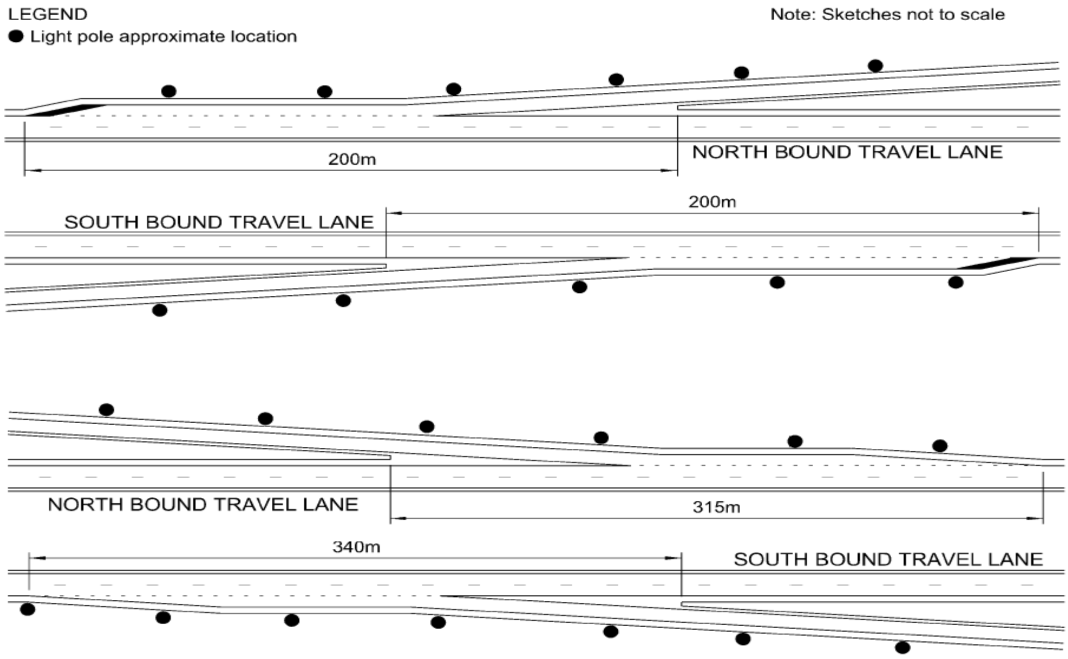

Figure 11: Newcastle Interchange lighting layout

Table 8: Newcastle Interchange data summary

Ramp location	Lighting conditions			Number of Accidents Recorded		
	CIL	PIL	No lighting	Day Time	Night Time	Other
Northbound Exit	☒	☐	☐	10	7	2
Northbound Entry	☒	☐	☐	8	1	3
Southbound Exit	☒	☐	☐	5	4	2
Southbound Entry	☒	☐	☐	0	3	0

3.3.2 SITE 2 – M1 – WEST WALLSEND INTERCHANGE

Site 2 West Wallsend Interchange is a half service interchange consisting of 2 ramps, a northbound exit ramp and a southbound entry ramp only. The exit ramp is 15m below the standard of 235m, whilst the entry ramp is also below the Austroads standards of 385m for an 110km/hr zone. The horizontal and vertical geometry at the interchange is sound with clear visibility to approaching exit ramps and sufficient site on entry ramps. The level of lighting provided on West Wallsend interchange ramps have been considered as partial lighting as the lights cover the merge and diverge area only and do not continue up the ramp until the intersection with the adjoining road. The schematic lighting layout can be seen in Figure 12. The total number of crashes occurring at the West Wallsend interchange is 16, with 62.5% occurring during daylight, Table 9 is a summary of the lighting conditions and number of crashes occurring on each ramp, the full detailed crash report is shown in Appendix C.

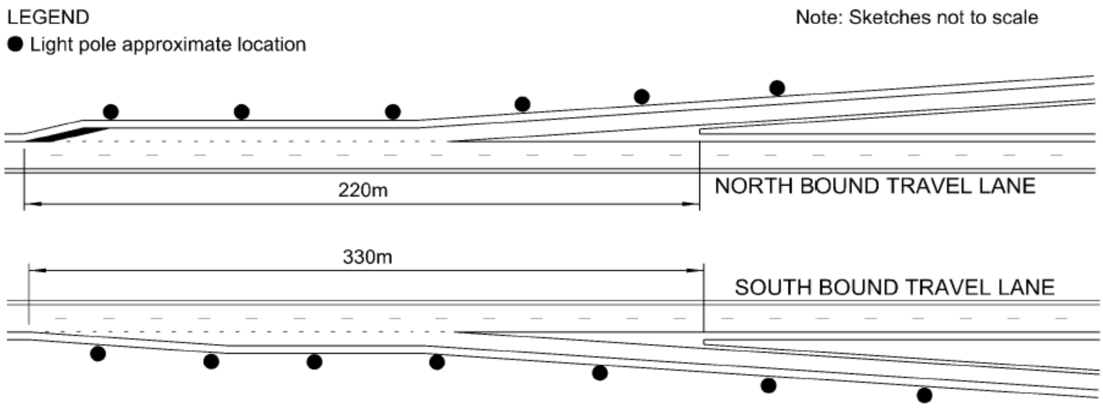

Figure 12: West Wallsend Interchange lighting layout

Table 9: West Wallsend Interchange data summary

Ramp location	Lighting conditions			Number of Accidents Recorded		
	CIL	PIL	No lighting	Day Time	Night Time	Other
Northbound Exit	☐	☒	☐	5	1	2
Southbound Entry	☐	☒	☐	5	1	2

3.3.3 SITE 3 – M1 – AWABA INTERCHANGE

Site 3 Awaba Interchange is a full service interchange consisting of 4 ramps, 2 northbound facing ramps and 2 southbound facing ramps. The northbound exit ramp, satisfies the Austroads standards where as the southbound exit ramp is 25m below the standard of 235m, whilst the entry ramps are also below the Austroads standards of 385m for an 110km/hr zone. The interchange is located in a vertical sag curve, on a straight horizontal alignment giving clear visibility to approaching exit ramps and sufficient site on entry ramps. The level of lighting provided on Awaba interchange varies with the exit ramps partially lit and the entry ramps having no lighting, the schematic lighting layout can be seen in Figure 13. The total number of crashes occurring at Awaba interchange is 32, with 56% occurring during daylight, Table 10 is a summary of the lighting conditions and number of crashes occurring on each ramp, the full detailed crash report is shown in Appendix C.

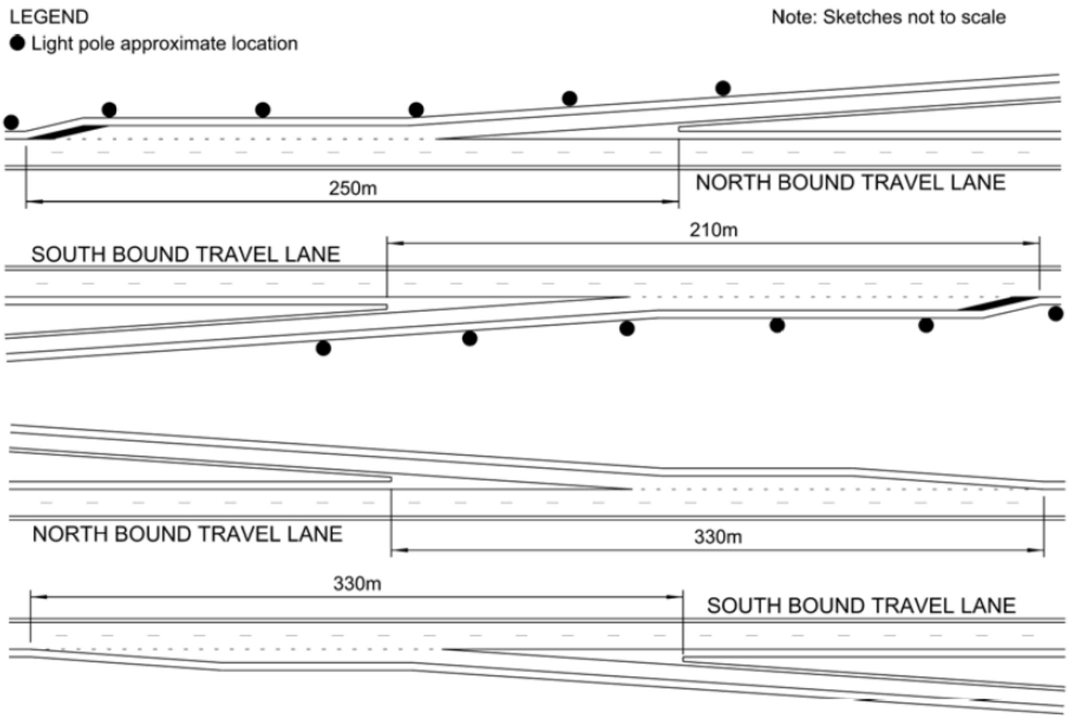

Figure 13: Awaba Interchange lighting layout

Table 10: Awaba Interchange data summary

Ramp location	Lighting conditions			Number of Accidents Recorded		
	CIL	PIL	No lighting	Day Time	Night Time	Other
Northbound Exit	☐	☒	☐	9	4	0
Northbound Entry	☐	☐	☒	4	3	3
Southbound Exit	☐	☒	☐	1	1	1
Southbound Entry	☐	☐	☒	4	2	0

3.3.4 SITE 4 – M1 – FREEMANS DR INTERCHANGE

Site 4 Freemans Dr Interchange is a half service interchange consisting of 2 ramps, a northbound exit ramp and a southbound entry ramp only. The exit ramp is 35m below the standard of 235m, whilst the entry ramp is also below the Austroads standards of 385m for an 110km/hr zone. The horizontal and vertical geometry at the interchange is sound with clear visibility to approaching exit ramps and sufficient site on entry ramps. No lighting has provided on Freemans Dr interchange ramps, the schematic lighting layout can be seen in Figure 14. The total number of crashes occurring at Freemans Dr interchange is 13, with 69% occurring during daylight, Table 11 is a summary of the lighting conditions and number of crashes occurring on each ramp, the full detailed crash report is shown in Appendix C.

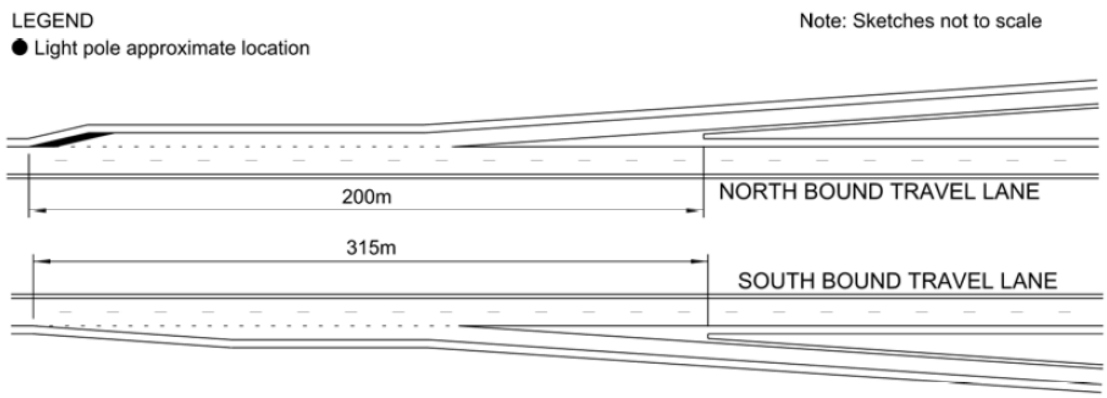

Figure 14: Freemans Dr Interchange lighting layout

Table 11: Freemans Dr Interchange data summary

Ramp location	Lighting conditions			Number of Accidents Recorded		
	CIL	PIL	No lighting	Day Time	Night Time	Other
Northbound Exit	☐	☐	☒	4	1	1
Southbound Entry	☐	☐	☒	5	1	1

3.3.5 SITE 5 – M1 – MORISSET INTERCHANGE

Site 5 Morisset Interchange is a full service interchange consisting of 4 ramps, 2 northbound facing ramps and 2 southbound facing ramps. The southbound exit ramp, satisfies the Austroads standards where as the northbound exit ramp is 25m below the standard of 235m, The southbound exit ramp is unusually long considering the exit ramp is not positioned on a down hill grade, however the start of the exit ramp does occur on a large horizontal radius. The entry ramps are also below the Austroads standards of 385m for an 110km/hr zone. The southbound facing ramps (northbound exit and southbound entry ramps) entry and exit points are located on uphill vertical grade, making it hard for vehicles particularly articulated vehicles to reach the desired speed of 110km/hr before merging. The level of lighting provided on Morisset interchange varies with the exit ramps having no lighting and the entry ramps being completely lit, the schematic lighting layout is shown in Figure 15. The entry ramps in the merge area consists of 6 lights, with complete lighting selected as more lights have been provided on the ramp past the gore area as a merge lane from the right turn movement using the interchange overpass occurs on the entry ramps.

The total number of crashes occurring at Morisset interchange is 40, with 52% occurring during daylight, Table 12 is a summary of the lighting conditions and number of crashes occurring on each ramp, the full detailed crash report is shown in Appendix C.

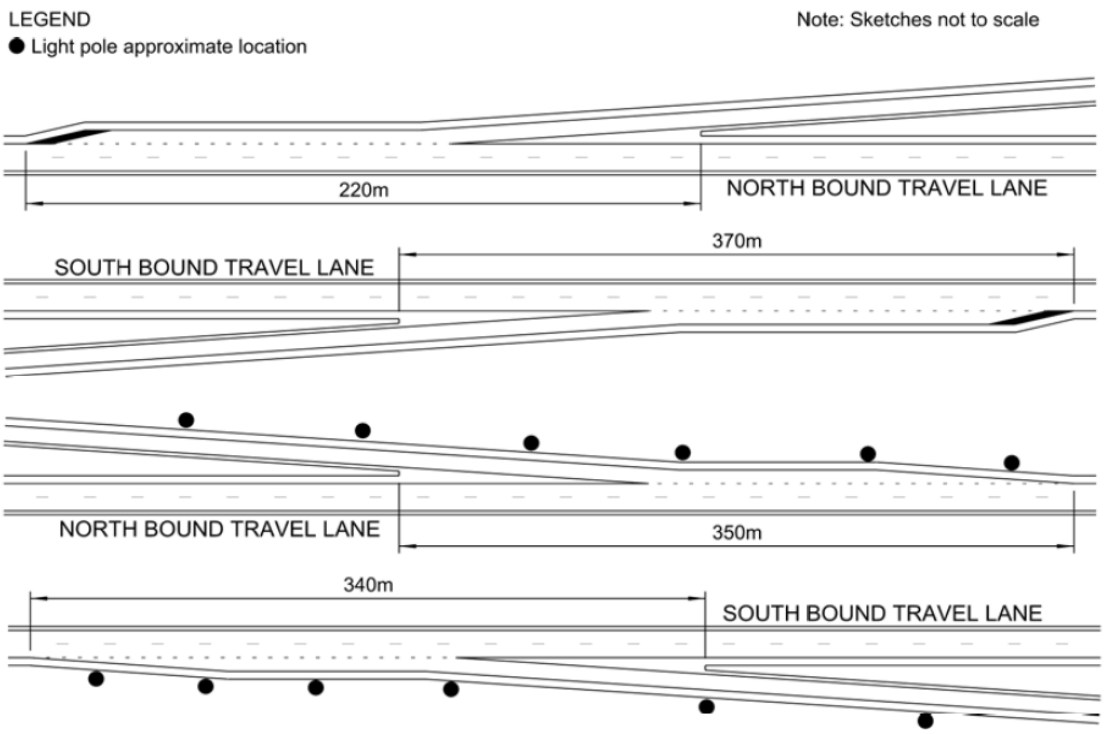

Figure 15: Morisset Interchange lighting layout

Table 12: Morisset Interchange data summary

Ramp location	Lighting conditions			Number of Accidents Recorded		
	CIL	PIL	No lighting	Day Time	Night Time	Other
Northbound Exit	☐	☐	☒	5	4	2
Northbound Entry	☒	☐	☐	7	3	0
Southbound Exit	☐	☐	☒	4	1	2
Southbound Entry	☒	☐	☐	5	5	2

3.3.6 SITE 6 – M1 – WARNERVALE INTERCHANGE

Site 6 Warnervale Interchange is a full service interchange consisting of 4 ramps, 2 northbound facing ramps and 2 southbound facing ramps. The exit ramps satisfy the Austroads standard of 235m. The southbound exit ramp is unusually long considering the exit ramp is not positioned on a down hill grade. The entry ramps are also below the Austroads standards of 385m for a 110km/hr zone. The level of lighting provided on Warnervale interchange varies with the exit ramps having no lighting and the entry ramps being completely lit, the schematic lighting layout is shown in Figure 16. The total number of crashes occurring at Warnervale interchange is 51, with 61% occurring during daylight, Table 13 is a summary of the lighting conditions and number of crashes occurring on each ramp, the full detailed crash report is shown in Appendix C.

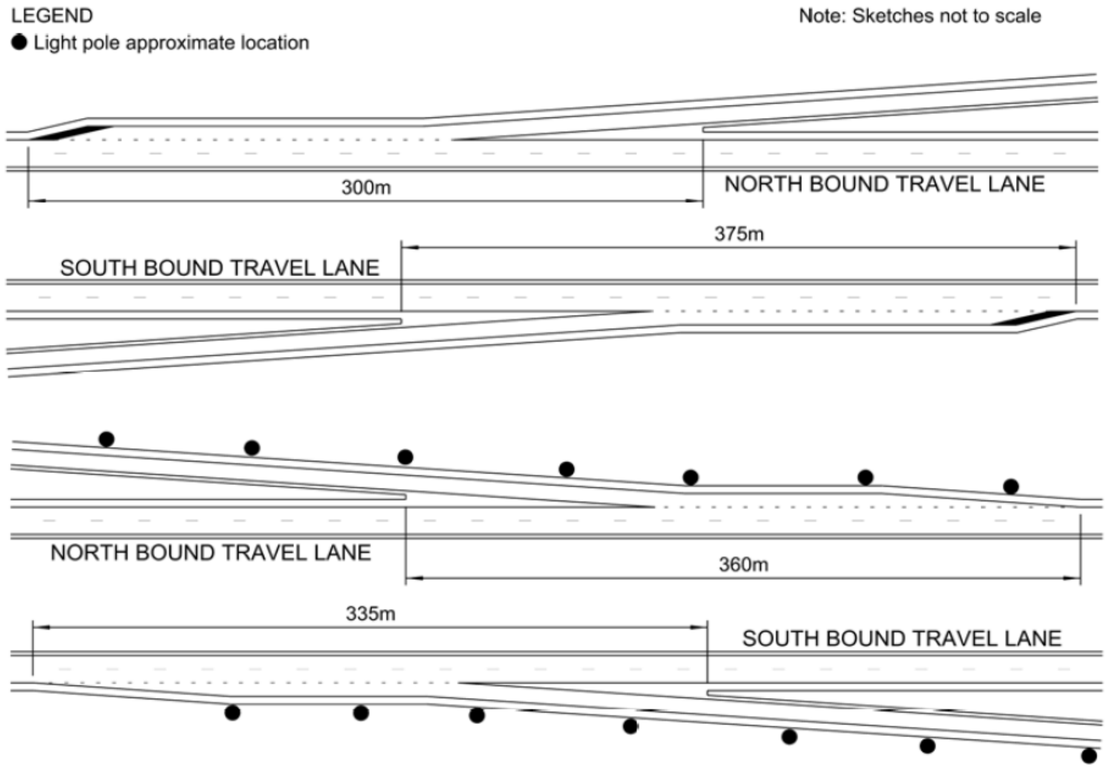

Figure 16: Warnervale Interchange lighting layout

Table 13: Warnervale Interchange data summary

Ramp location	Lighting conditions			Number of Accidents Recorded		
	CIL	PIL	No lighting	Day Time	Night Time	Other
Northbound Exit	☐	☐	☒	9	6	1
Northbound Entry	☒	☐	☐	2	2	0
Southbound Exit	☐	☐	☒	10	7	0
Southbound Entry	☒	☐	☐	10	3	1

3.3.7 SITE 7 – M1 – SERVICE CENTRE INTERCHANGE

Site 7 Service Centre Interchange is a full service interchange consisting of 4 ramps, 2 northbound facing ramps and 2 southbound facing ramps. The northbound and southbound exit ramps are 50m and 40m respectively short of the required 235m as per Austroads. The entry ramps are also below the Austroads standards of 385m for an 110km/hr zone. Complete interchange lighting is provided on the Service Centre interchange ramps, however the number of lights varies from 6 to 9 as shown on the schematic lighting layout in Figure 17. The total number of crashes occurring at the Service Centre interchange is 48, with 81% occurring during daylight, Table 14 is a summary of the lighting conditions and number of crashes occurring on each ramp, the full detailed crash report is shown in Appendix C.

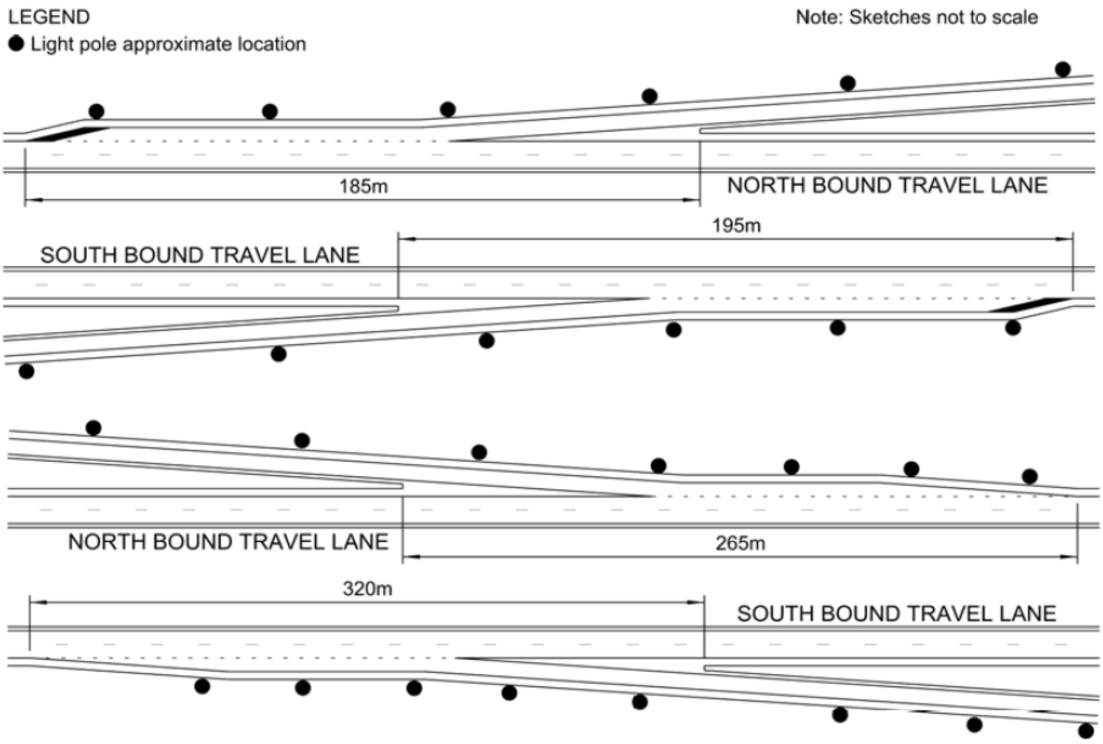

Figure 17: Service Centre Interchange lighting layout

Table 14: Service Centre Interchange data summary

Ramp location	Lighting conditions			Number of Accidents Recorded		
	CIL	PIL	No lighting	Day Time	Night Time	Other
Northbound Exit	☒	☐	☐	4	2	0
Northbound Entry	☒	☐	☐	14	3	0
Southbound Exit	☒	☐	☐	11	4	0
Southbound Entry	☒	☐	☐	10	0	0

3.3.8 SITE 8 – M1 – TUGGERAH INTERCHANGE

Site 8 Tuggerah Interchange is a full service interchange consisting of 4 ramps, 2 northbound facing ramps and 2 southbound facing ramps. The exit ramps satisfy the Austroads standard of 235m. The northbound exit ramp is unusually long considering the exit ramp is not positioned on a down hill grade. The entry ramps are also below the Austroads standards of 385m for an 110km/hr zone. The level of lighting provided on Tuggerah interchange varies with the exit ramps having no lighting and the entry ramps being completely lit, the schematic lighting layout is shown in Figure 18, it is interesting to note that an extra light has been placed in the gore area of both entry ramps and is providing luminance on to the M1 through traffic. Compared to other sites more light poles have been provided on the Tuggerah interchange entry ramps, with up 12 lights provided on the entire ramp. The total number of crashes occurring at Tuggerah interchange is 113, with 74% occurring during daylight, Table 15 is a summary of the lighting conditions and number of crashes occurring on each ramp, the full detailed crash report is shown in Appendix C.

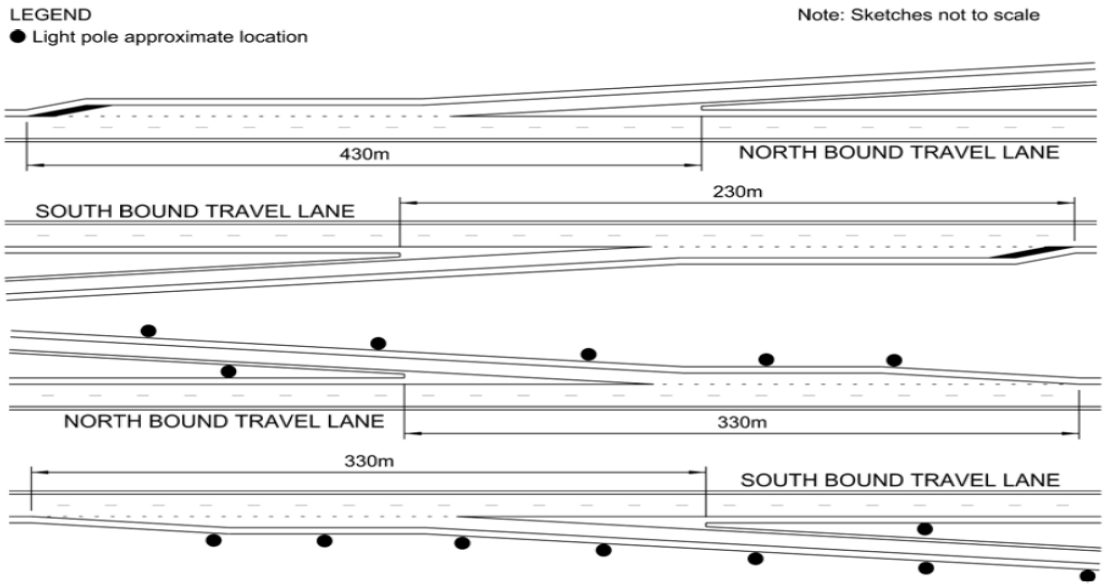

Figure 18: Tuggerah Interchange lighting layout

Table 15: Tuggerah Interchange data summary

Ramp location	Lighting conditions			Number of Accidents Recorded		
	CIL	PIL	No lighting	Day Time	Night Time	Other
Northbound Exit	☐	☐	☒	25	13	1
Northbound Entry	☒	☐	☐	46	8	2
Southbound Exit	☐	☐	☒	6	2	1
Southbound Entry	☒	☐	☐	7	1	1

3.3.9 SITE 16 – M1 – Mt COLAH INTERCHANGE

Site 16 Mt Colah Interchange is a half service interchange consisting of 2 ramps, a northbound exit ramp and a southbound entry ramp only. The exit ramp is 10m below the standard of 235m but is on an uphill grade allowing for reduction in deceleration length due to grade correction. The entry ramp is also below the Austroads standards of 385m for an 110km/hr zone but is on a downhill grade improving vehicles acceleration rates and hence reaching the required speed quicker. The horizontal and vertical geometry at the interchange is sound with clear visibility to approaching exit ramps and sufficient site on entry ramps. No lighting has provided on the exit ramp, however 14 lights have been provided on the entry ramp, the schematic lighting layout can be seen in Figure 19. The total number of crashes occurring at Mt Colah interchange is 61, with 66% occurring during daylight, Table 16 is a summary of the lighting conditions and number of crashes occurring on each ramp, the full detailed crash report is shown in Appendix C.

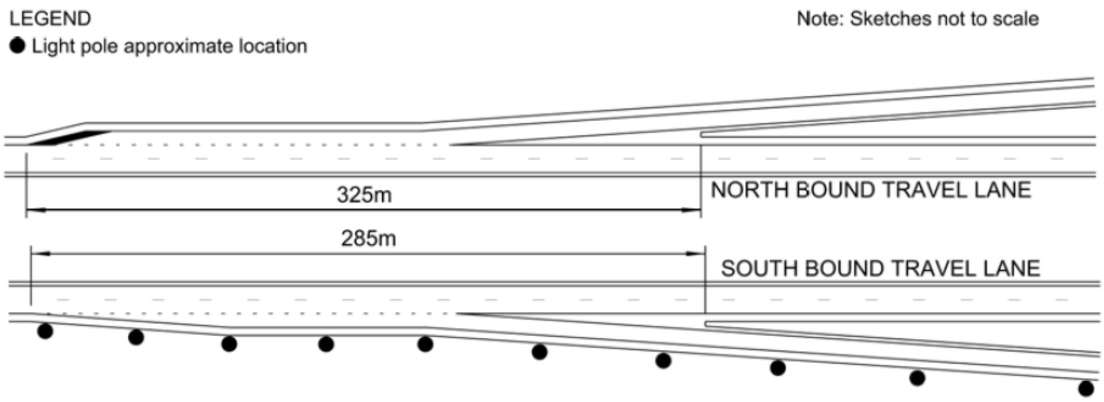

Figure 19: Mt Colah Interchange lighting layout

Table 16: Mt Colah Interchange data summary

Ramp location	Lighting conditions			Number of Accidents Recorded		
	CIL	PIL	No lighting	Day Time	Night Time	Other
Northbound Exit	☐	☐	☒	17	10	4
Southbound Entry	☒	☐	☐	23	7	0

4. RESULTS AND ANALYSIS

Using the data collected from site visits and accident records for the selected 9 sites, an analysis was conducted to determine the effectiveness of street lighting on grade separated interchange ramps. Particularly if there was a reduction in night time accidents at diverge and merge areas of grade separated interchanges.

The first step was to determine how many crashes were occurring during the day and night of the 419 crashes occurring in diverge and merge areas for the selected 9 sites. The results showed that 275 crashes occurred during daylight, with the other 144 occurring during darkness or other, which are crashes during dusk or dawn.

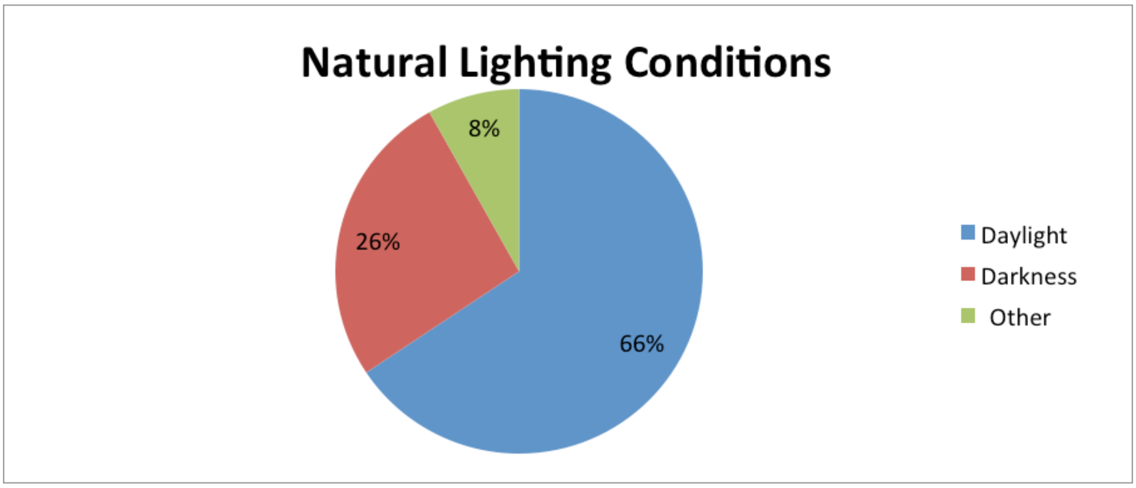

Figure 20: M1 Study - Crashes Vs. Natural Lighting Conditions

A comparison was done to show the number of crashes on exit ramps compared to the number of crashes on entry ramps to determine if crashes at diverge and merge areas on the M1 reflect the trend found in the literature review. That being that most accidents on grade separated interchanges occur on exit ramps. As illustrated in Figure 21 of all the accidents on the 9 interchanges along the M1 there was a 50% split between accidents on exit and entry ramps, going against the trend from previous studies.

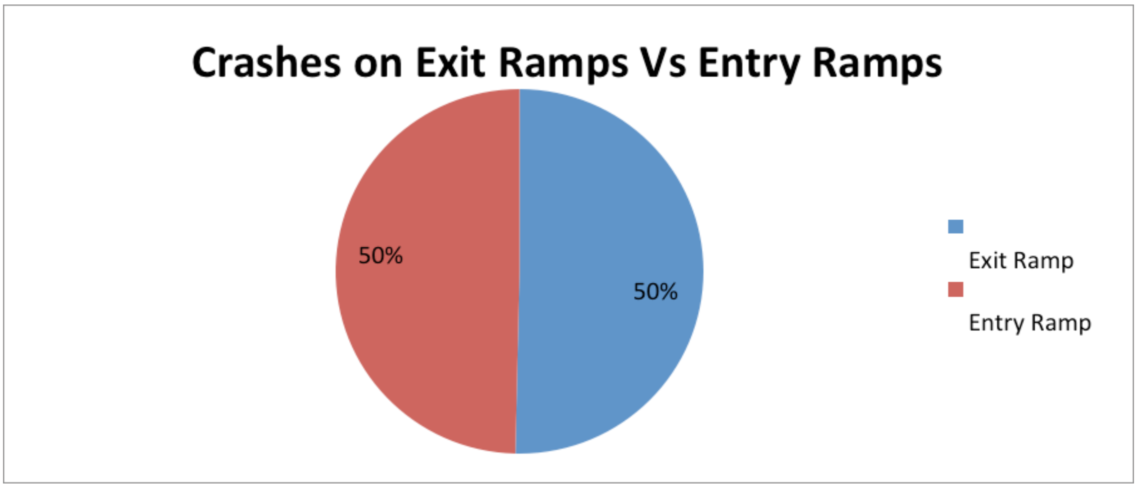

Figure 21: M1 Study - Crashes on Exit Ramps Vs. Entry Ramps

Figure 22 and Figure 23 show the breakdown of crashes on only exit and entry ramps respectively and the natural lighting conditions recorded at the time of the accidents. The results show that both exit and entry ramps have a higher number of crashes during the day compared to night, with 72% of the 208 accidents recorded on the 15 interchange entry ramps occurring during daylight.

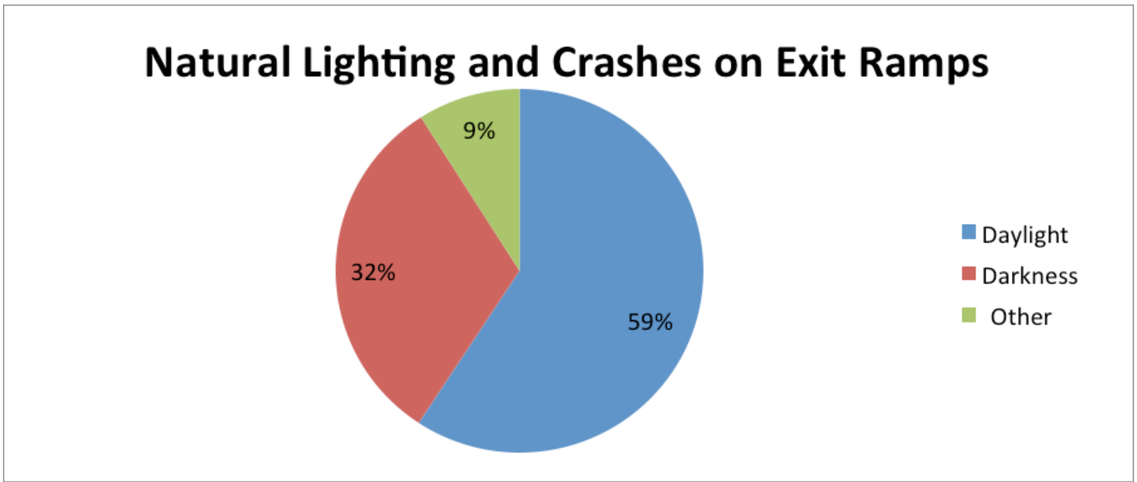

Figure 22: M1 Study - Natural Lighting Conditions on Exit Ramp Crashes

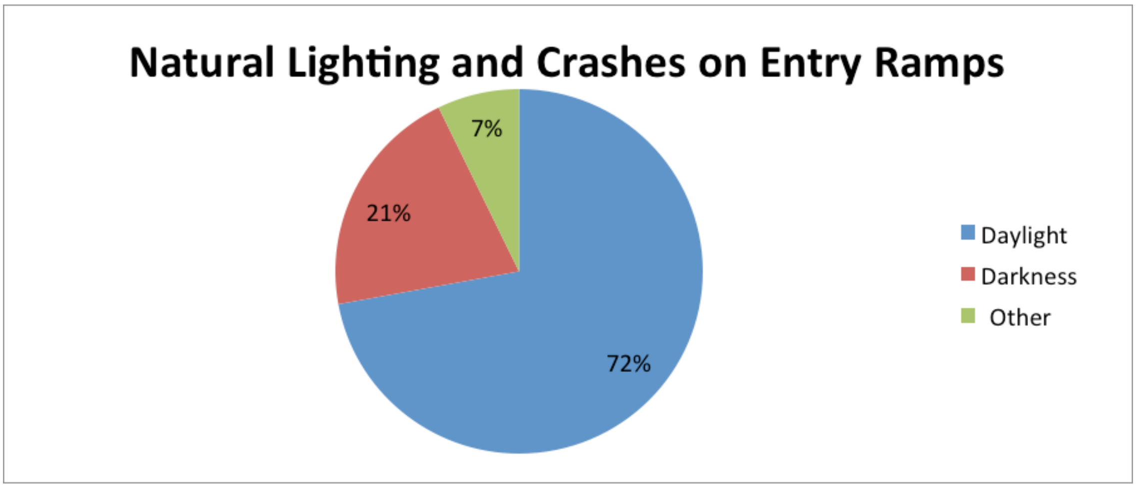

Figure 23: M1 Study - Natural Lighting Conditions on Entry Ramp Crashes

4.1 CRASH TYPES

Previous studies have found that the most common crash type is rear end collisions for merge manoeuvres and that for exit ramps, the most common type of crash is run-off type crashes. The results from the crash data collected on the M1 show that for exit ramps 112 crashes were run-off type crashes either veering off to the left or right. Interestingly the most common type of crash for entry ramps on the M1 was also run-off type crashes with 111 crashes out of 208 crashes, however the majority of run-off type crashes were vehicles veering off to the right indicating the possibility that as vehicles are on the entry ramp about to merge, vehicles travelling on the through road are paying attention to the merging vehicle and moving over to allow room but getting into trouble themselves or causing another vehicle off the road. Figure 24 and Figure 25 show the total number or crashes and crash types for exit ramps and entry ramps respectively on M1 interchanges.

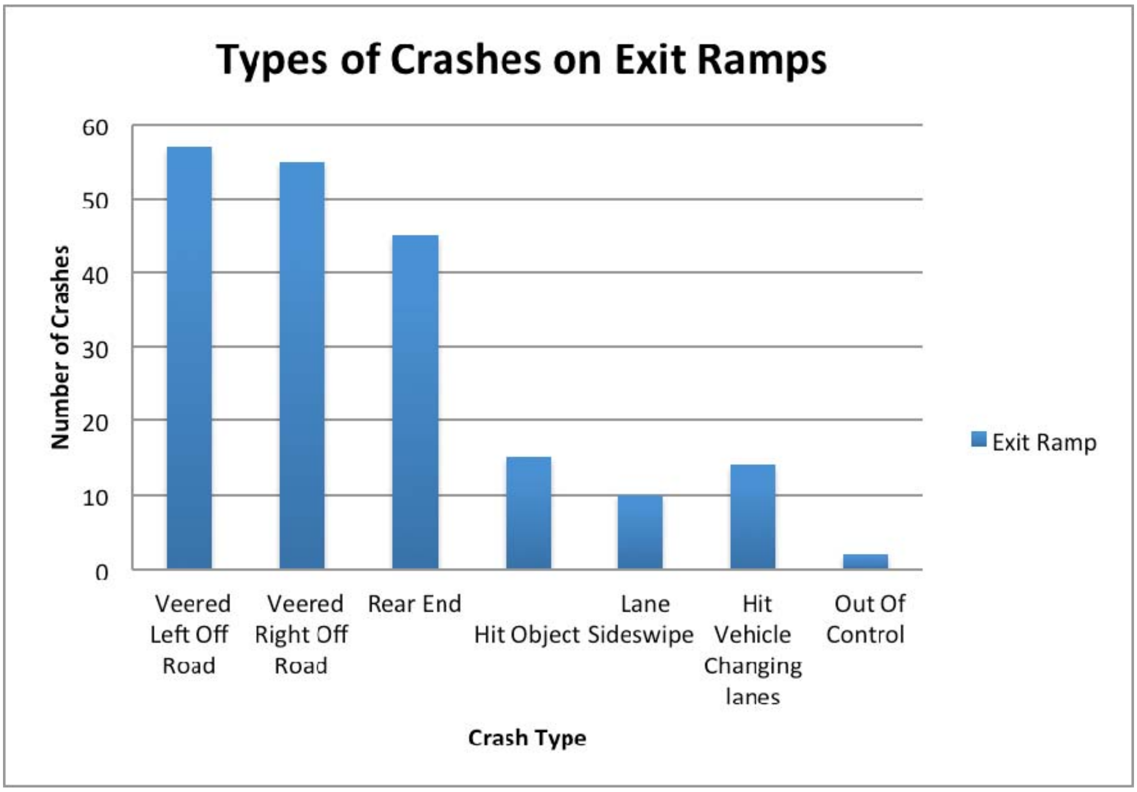

Figure 24: M1 Study - Exit Ramp Crash Types

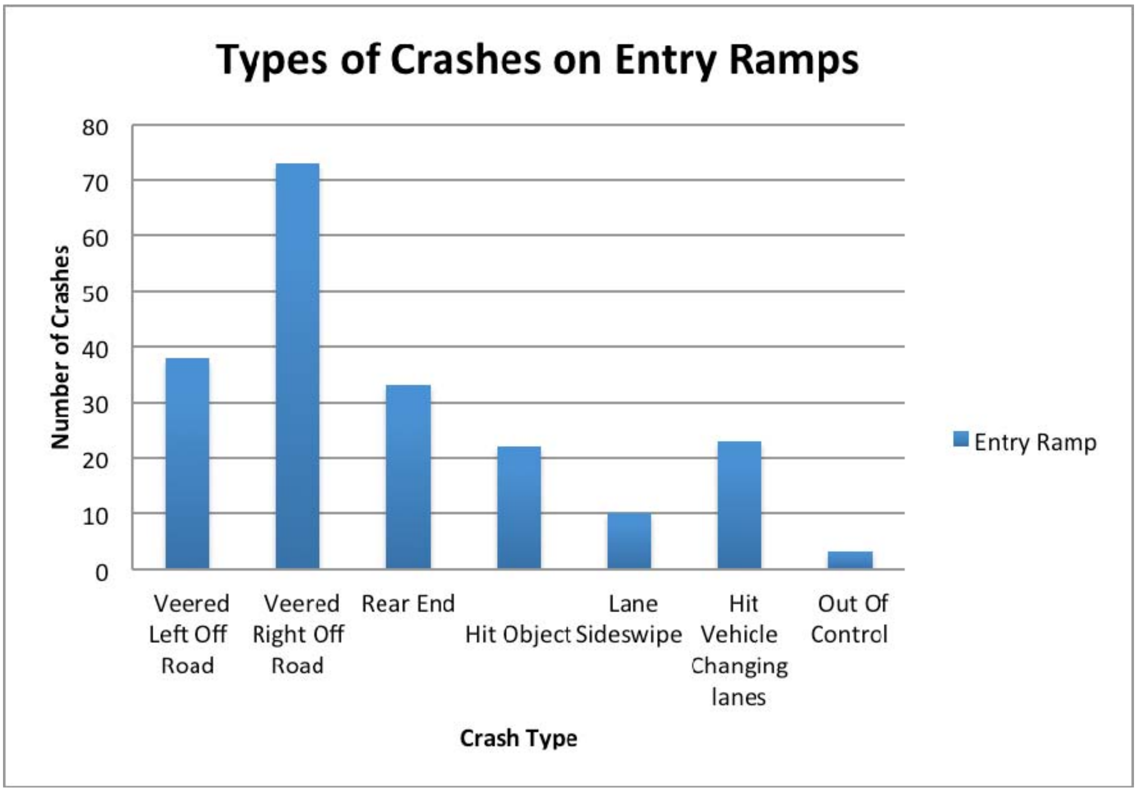

Figure 25: M1 Study - Entry Ramp Crash Types

4.1.1 Crash Types – Day Time

To compare the type off accidents occurring on exit and entry ramps during the day and night, the crashes occurring during the day must be analysed to determine if the same types of crashes are occurring during the night or if street lightings are helping reduce accidents.

Selecting only the crashes during day time for exit and entry ramps it was found that the most common type of crash on the M1 exit ramps was run-off road type, with vehicles commonly veering of the road to the left. Run-off type crashes with vehicles veering off to the right were the most common type of crash for vehicles using entry ramps on the M1. Figure 26 shows the breakdown of the 275 crashes occurring on exit and entry ramps during day time and the types of crashes occurring.

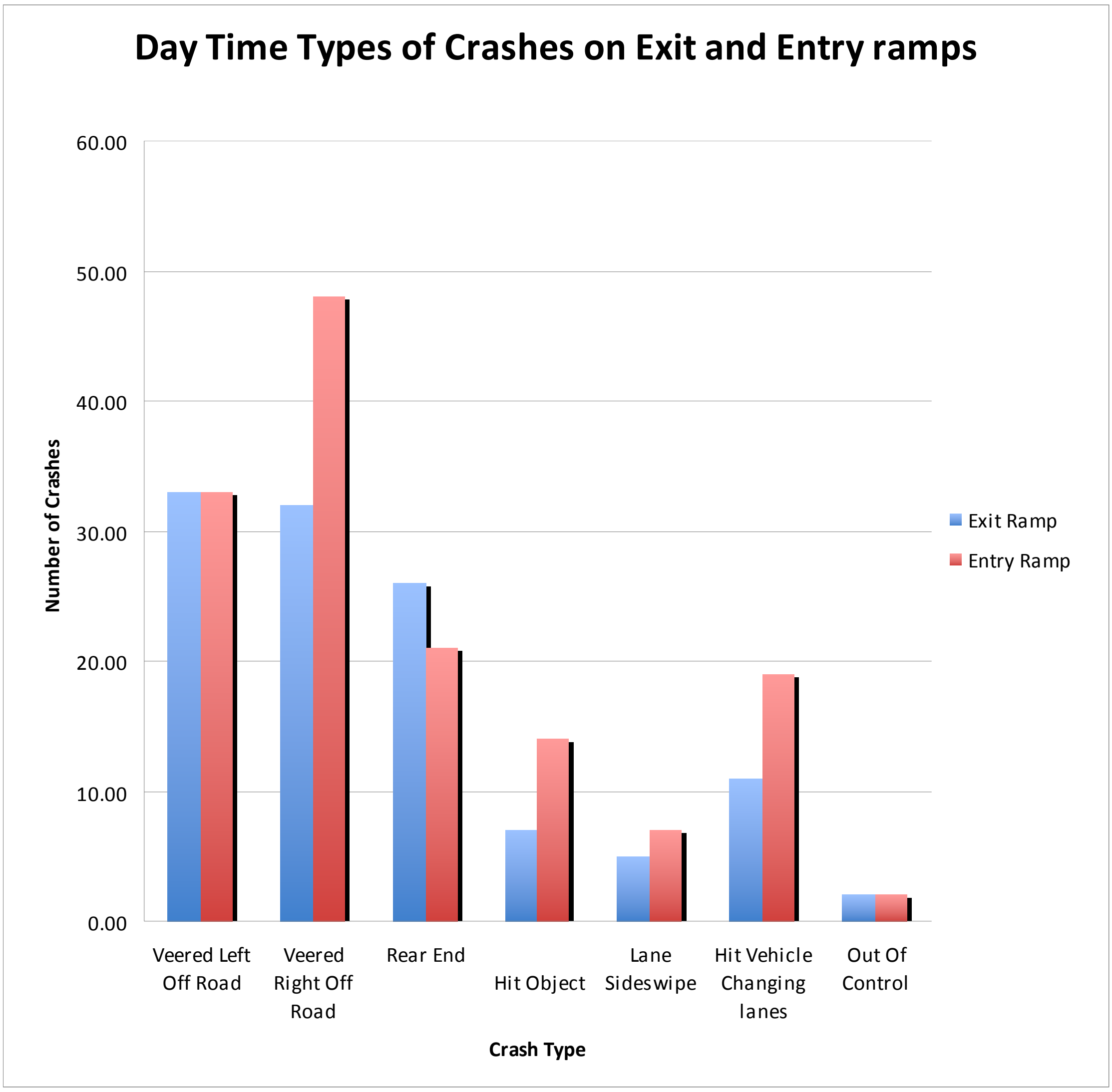

Figure 26: M1 Study - Day Time Crashes on Exit and Entry Ramps

4.1.2 Crash Types – Night Time

Selecting only the crashes during night time for exit and entry ramps it was found that the most common type of crash on the M1 exit ramps was run-off road type, with vehicles commonly veering of the road to the left. Run-off type crashes with vehicles veering off to the right were the most common type of crash for vehicles using entry ramps on the M1. Figure 27 shows the breakdown of the 144 crashes occurring on exit and entry ramps during night time and the types of crashes occurring. Interestingly the most common type of crash occurring during daylight, run-off type crash, is the most common crash at night time.

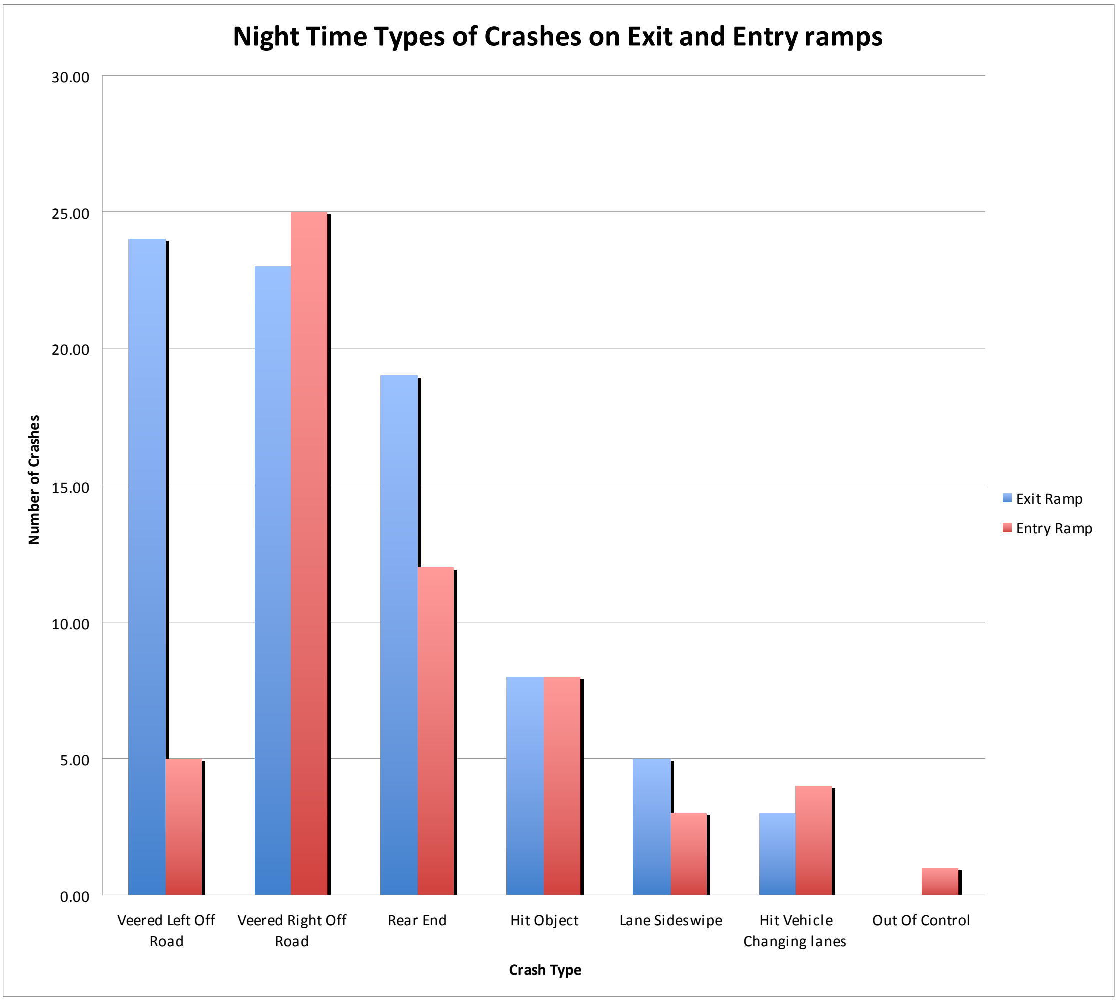

Figure 27: M1 Study - Night Time Crashes on Exit and Entry Ramps

4.1.3 Crash Types - Daytime Vs Night Time

Figure 28 shows a comparison of crashes on exit ramps during the day and night, the results show that the same types of crashes are occurring on exit ramps during the day and night although there is a reduction in numbers, however the reduction of accidents could be due to the decrease in traffic volumes at night time. Of the 7 common crash types occurring on exit ramps, the is an increase in “Hit Object” at night time compared to day night, which could be directly related to drivers not being able to see objects on the road at night clearly.

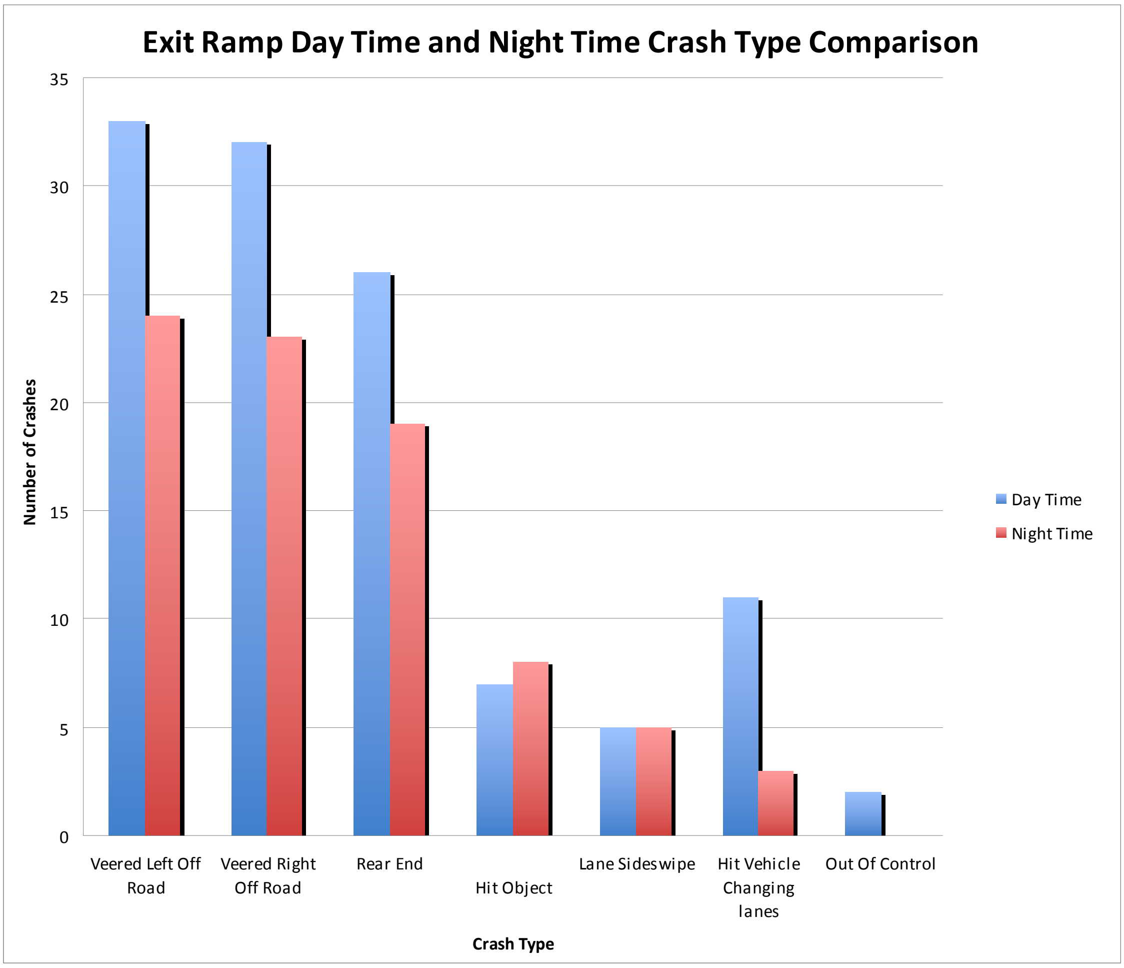

Figure 28: M1 Study - Exit Ramp Day and Night Crash Type Comparison

Figure 29 shows a comparison of crashes on entry ramps during the day and night, the results show a slight variation in types of accidents occurring, run-off type crashes with vehicles veering of the road to the right is still the most common occurring crash type, however rear end collisions and hit objects have become the second and third highest crash types at night time respectively. Rear end collisions are not directly related to street lighting or lack of street light, but more to driver awareness and behaviour when about to perform a merging manoeuvrer.

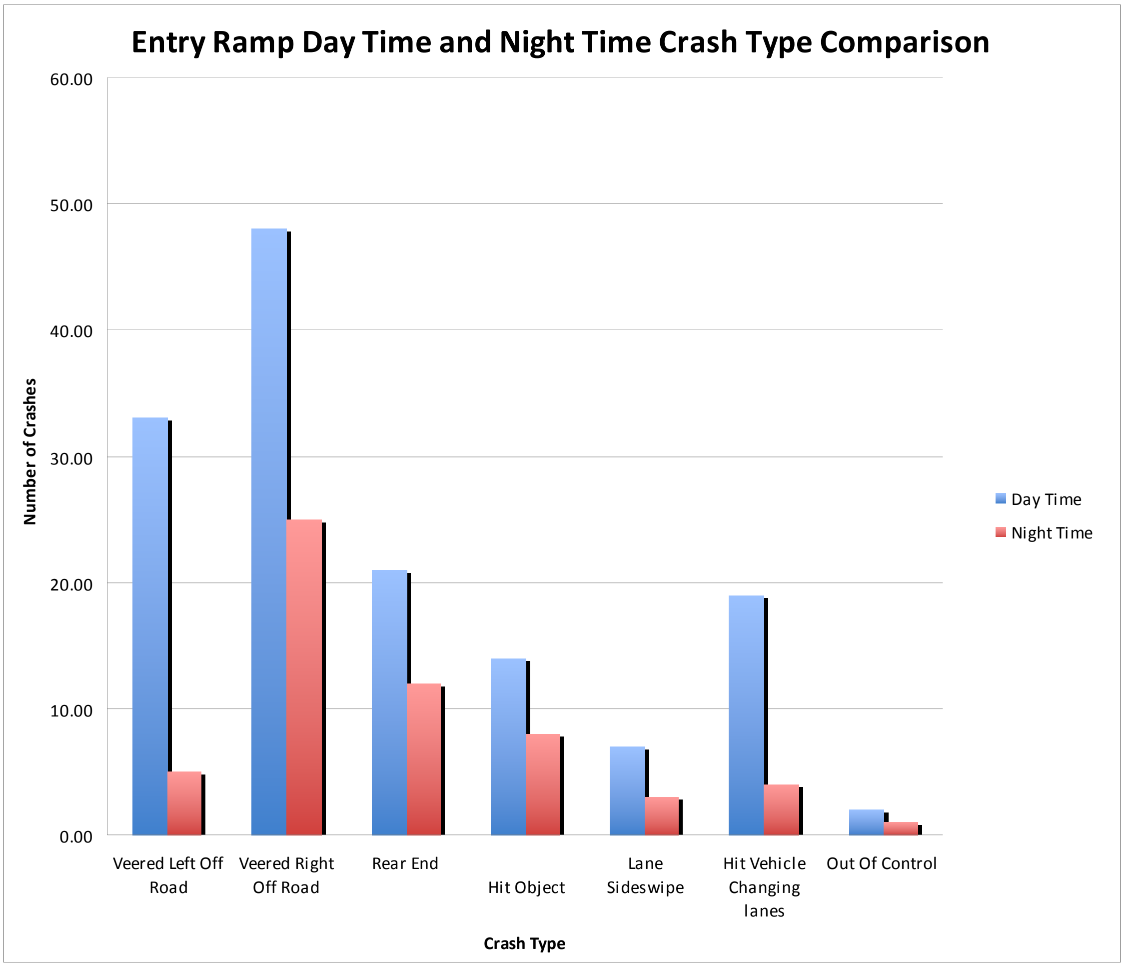

Figure 29: M1 Study - Entry Ramp Day and Night Crash Type Comparison

4.2 ANALYSIS OF LIT AND UNLIT EXIT RAMPS

To determine if street lighting has a positive effect on safety on interchange exit ramps and reduces accident rates, a comparison was done to compare the exit ramps that have street lighting installed on the number and types of crashes occurring during the day and a night. Figure 30 shows the number of crashes and types of crashes occurring on the 7 lit exit ramps, comparing the day and night time crashes. It can be seen that there is an overall reduction in night time accidents however with the presence of street lighting at night time there were 4 "Hit Object" crashes and none during the day, one would think lighting would benefit drivers and enable them to see objects on the road at night easier. Street lighting on exit ramps has a seen a reduction in vehicles hitting another vehicle whilst changing lanes, but this could also be due to the reduced traffic volumes at night.

Figure 31 shows the number and types of crashes occurring on the 8 unlit exit ramps comparing the day and night time crashes. The figure illustrates that there is an overall reduction in night time accidents, but the same crash types are occurring regardless of day or night time. Due to more "Hit Object" type crashes occurring at night time on lit exit ramps would indicate that street lighting has no significant effect in reducing night time accidents, however there was a reduction in run-off type crashes on lit exit ramps with only 22 occurring compared to 27 on unlit exit ramps at night time, indicating that the provision of lights is aiding drivers to perform a diverge manoeuvre safely, possibly cause they can see the exit ramp ahead and have time to prepare to diverge.

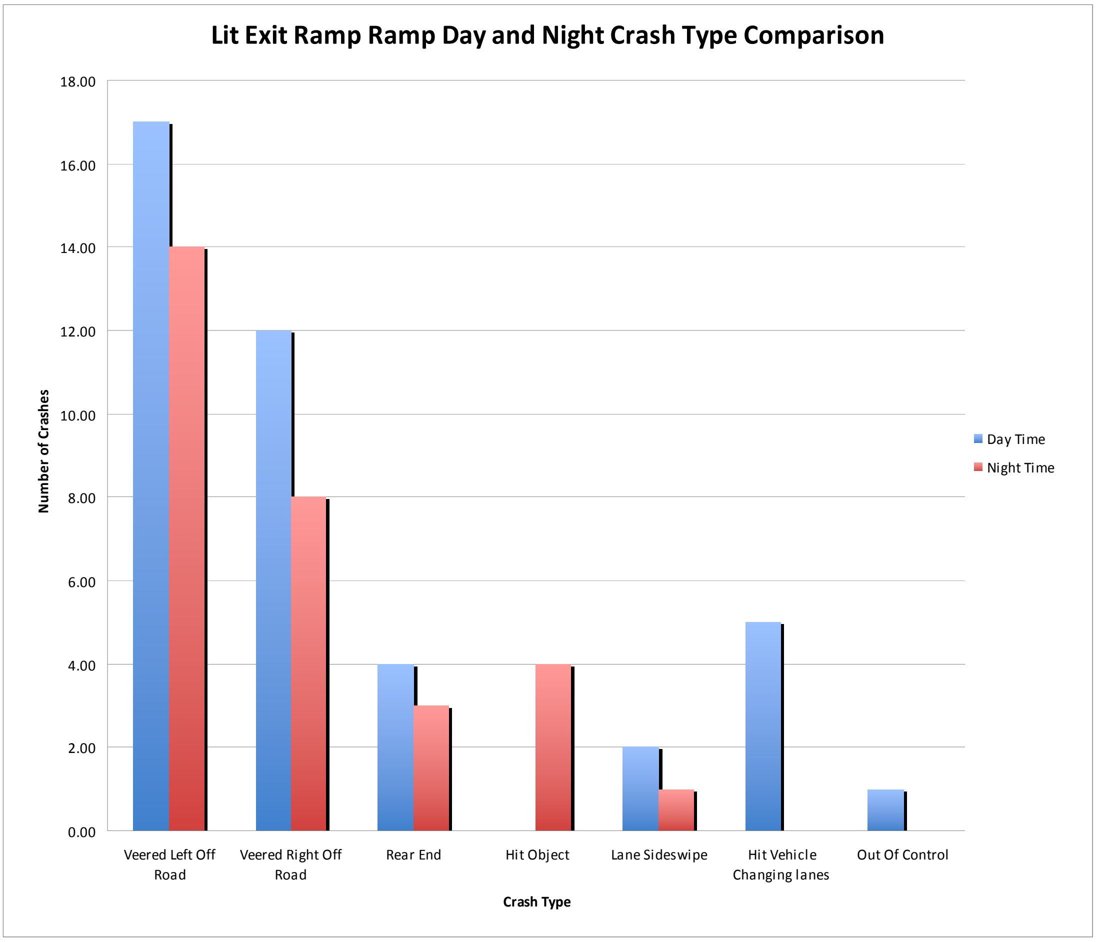

Figure 30: M1 Study - Lit Exit Ramp Day and Night Crash Type Comparison

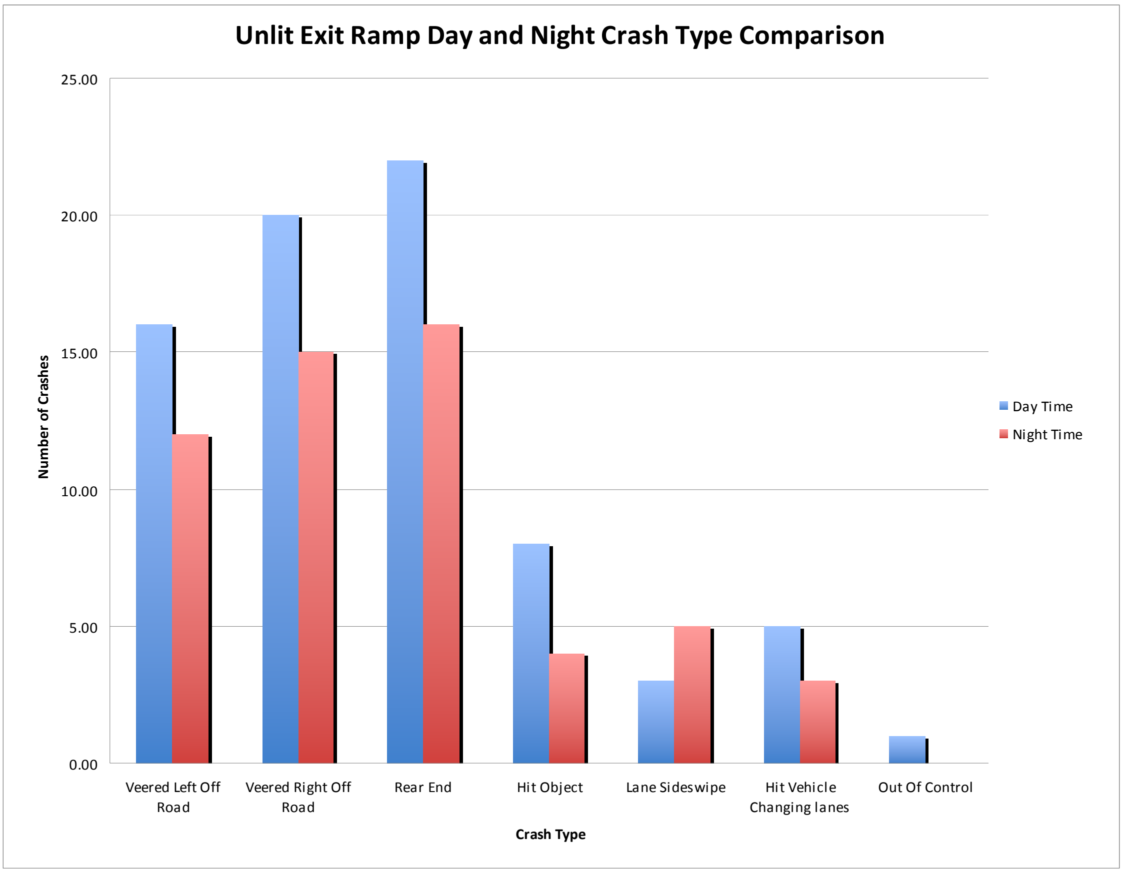

Figure 31: M1 Study - Unlit Exit Ramp Day and Night Crash Type Comparison

4.3 ANALYSIS OF LIT AND UNLIT ENTRY RAMPS

To determine if street lighting has a positive effect on safety on interchange entry ramps and reduces accident rates, a comparison was done to compare the entry ramps that have street lighting installed on the number and types of crashes occurring during the day and a night. Figure 32 shows the number of crashes and types of crashes occurring on the 12 lit entry ramps, comparing the day and night time crashes it can be seen that there is an overall reduction in night time accidents. Figure 33 shows the number of crashes and types of crashes on the 3 unlit entry ramps, from the data collected there is a reduction in the number of night time crashes compared to day time, but it’s difficult to assess accurately with out more unlit sites being assessed.

Comparing the number of run-off type crashes on both lit and unlit entry ramps it can be seen that 7 occur on unlit entry ramps giving an average of 2.3 run-off type crashes per unlit entry ramp, whilst on lit entry ramps there was 23 run-off type crashes giving an average of 1.9 run-off type crashes per lit entry ramp. This indicates there is marginal safety benefit in providing street lighting in the merge are on interchange entry ramps.

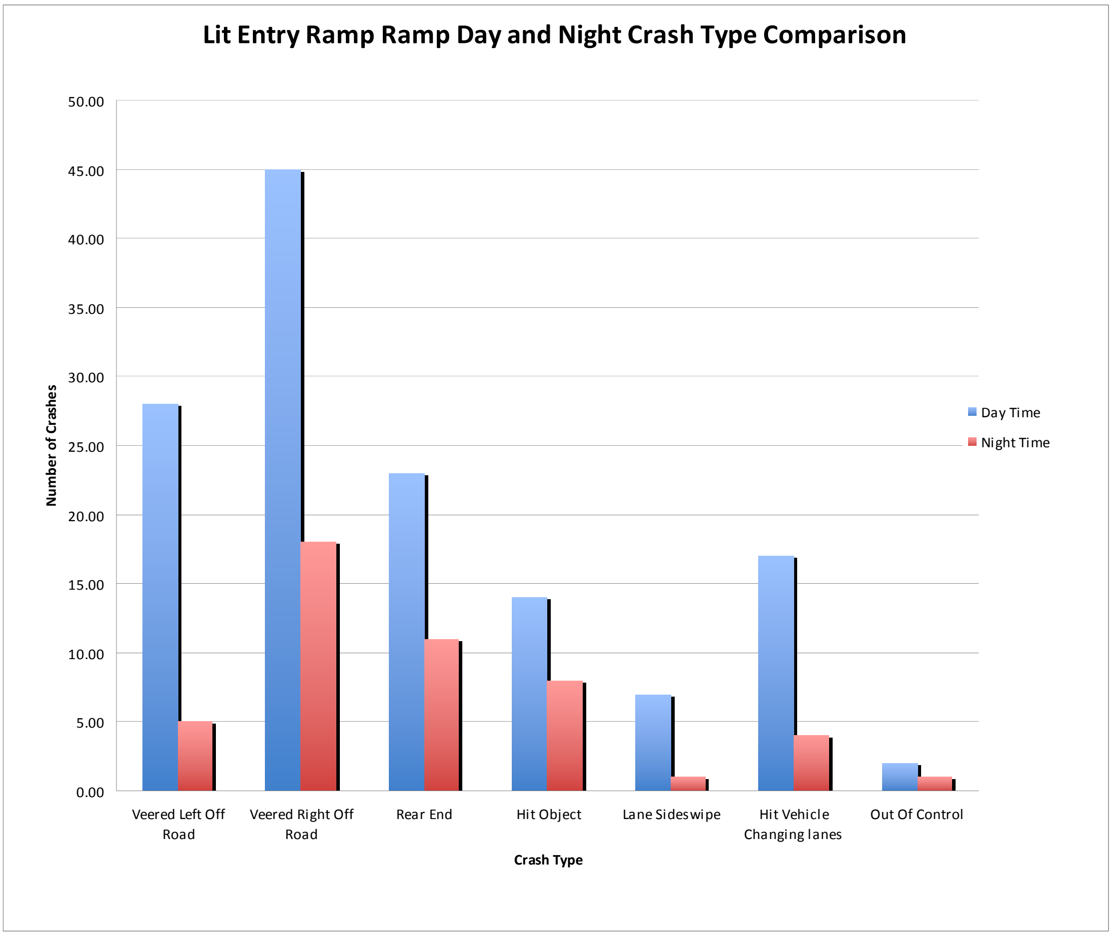

Figure 32: M1 Study - Lit Entry Ramp Day and Night Crash Type Comparison

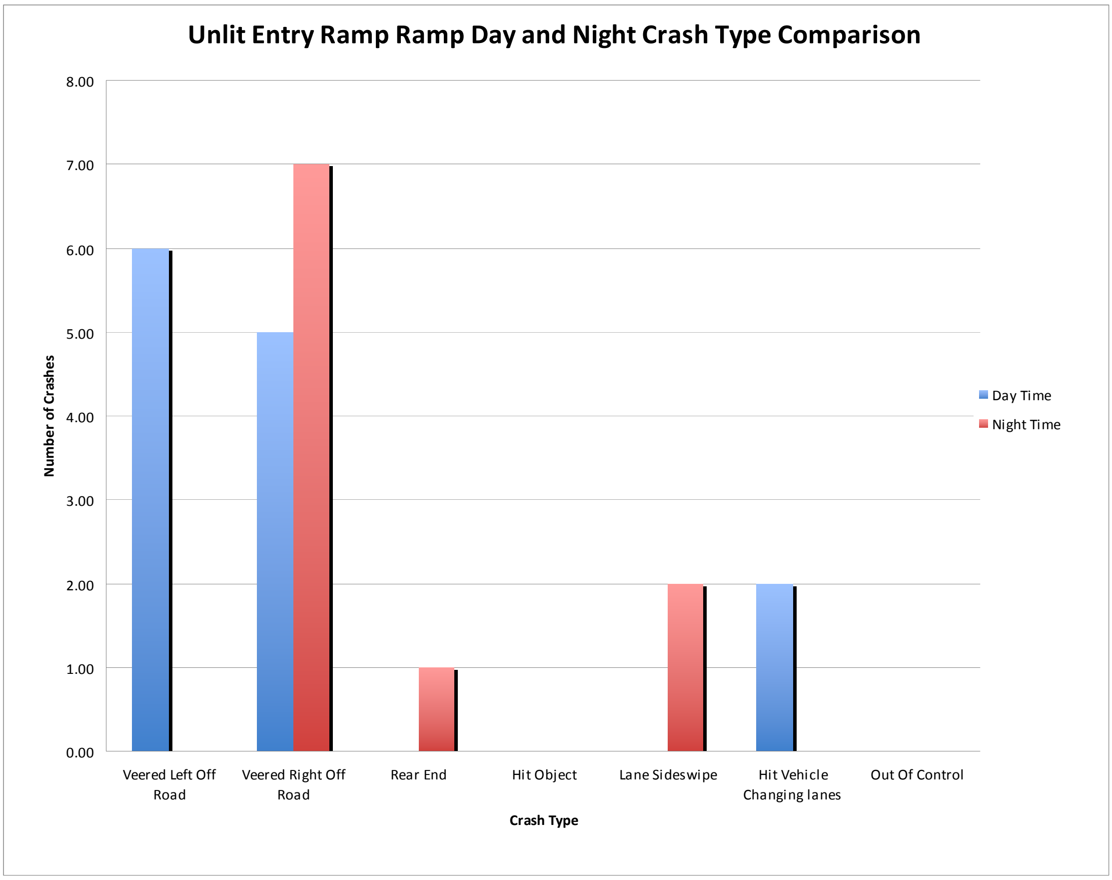

Figure 33: M1 Study - Unlit Entry Ramp Day and Night Crash Type Comparison

4.4 SEVERITY OF CRASHES

Previous studies have found that the provision of street lighting doesn't necessarily reduce the number of accidents but reduces the severity of accidents. On the study of the M1 the level of severity of crashes on exit ramps did not change dramatically between day time and night time with both recording 2 fatalities, however when the crashes occurring on exit ramps during night was broken down to lit and unlit ramps as shown in Table 18 it is obvious that there is a significant reduction in the severity of accidents on lit ramps with a 200% increase in fatality accidents and a 52% increase in injury accidents on unlit exit ramps compared to lit ramps.

Table 17: M1 Study - Severity of Crashes on Exit Ramps

Severity of crashes on exit ramps			
	Tow away	Injury	Fatal
Day time	71	47	2
Night time	46	36	2

Table 18: M1 Study - Severity of Night Time Crashes on Exit Ramps

Severity of night time crashes on exit ramps			
	Tow away	Injury	Fatal
Lit ramps	19	11	0
Unlit ramps	31	23	2

The severity of crashes occurring on entry ramps from the results indicates no significant reduction in crash severity from the day time to the night time with 27% of crashes during the day being injury crashes compared to 25% of all night time crashes being injury crashes. Looking at the severity of night time crashes on lit and unlit entry ramps, as shown in Table 20 and taking average crashes per ramp due to a positive skew towards lit entry ramps there is 1 injury crash per lit entry ramp and 0.6 injury crashes per unlit ramps, indicating regardless of the provision of street lighting on entry ramps the severity of crashes on entry ramps remains similar.

Table 19: M1 Study - Severity of Crashes on Entry Ramps

Severity of crashes on entry ramps			
	Tow away	Injury	Fatal
Day time	104	39	2
Night time	44	15	0

Table 20: M1 Study - Severity of Night Time Crashes on Entry Ramps

Severity of night time crashes on entry ramps			
	Tow away	Injury	Fatal
Lit ramps	36	13	0
Unlit ramps	8	2	0

4.5 ANALYSIS OF NIGHT TIME CRASHES

With 34% of the crashes recorded for the 9 sites occurring during at night time, it was crucial to analysis the crashes occurring during darkness or other (dusk and dawn) to determine if street lighting was installed, the weather conditions, other contributing factors and type of crash to accurately assess if street lighting at interchange exit and entry ramps is an affective solution to reduce accidents.

Fine and dry weather conditions made up 61% of the 144 night time accidents, with 32% of the accidents occurring during raining conditions, indicating that night time accidents occur regularly regardless of the weather conditions, implying that street lighting may reduce night time accident rates.

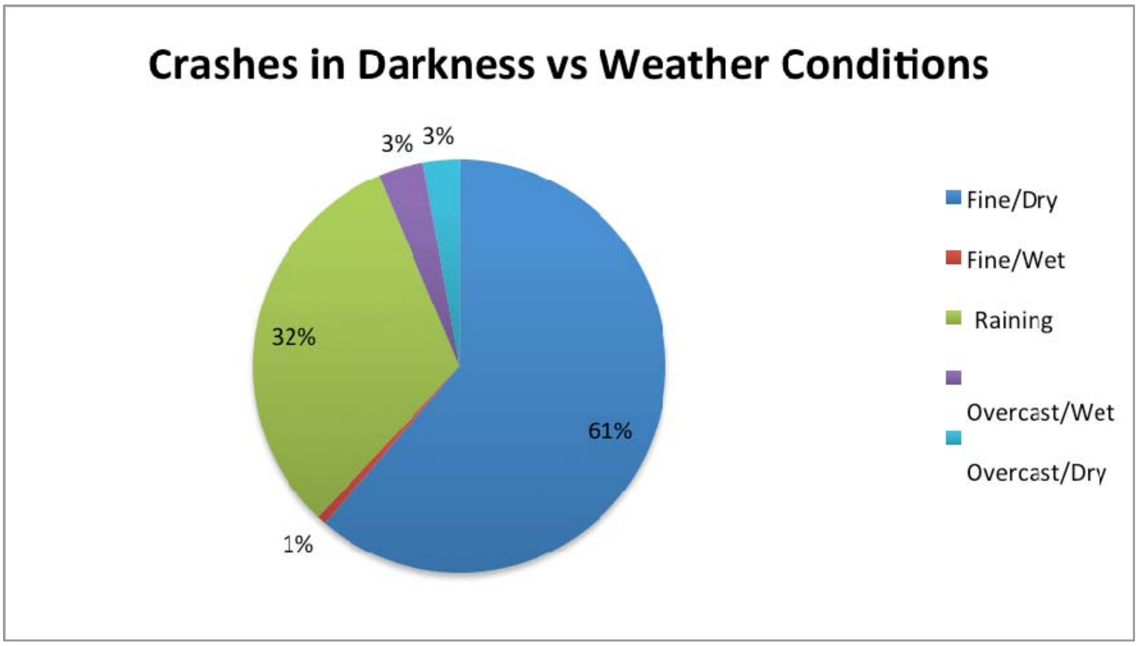

Figure 34: M1 Study - Night Time Crashes and Weather Conditions

Fatigue, Speed, Alcohol or a combination are common contributing factors to crashes, the crashes recorded at night time on the M1 showed that 68% of the crashes had no contributing factors as seen in Figure 35. This indicates that the majority of crashes at night are occurring due driver error, which could be due to the lack of lighting and poor visibility.

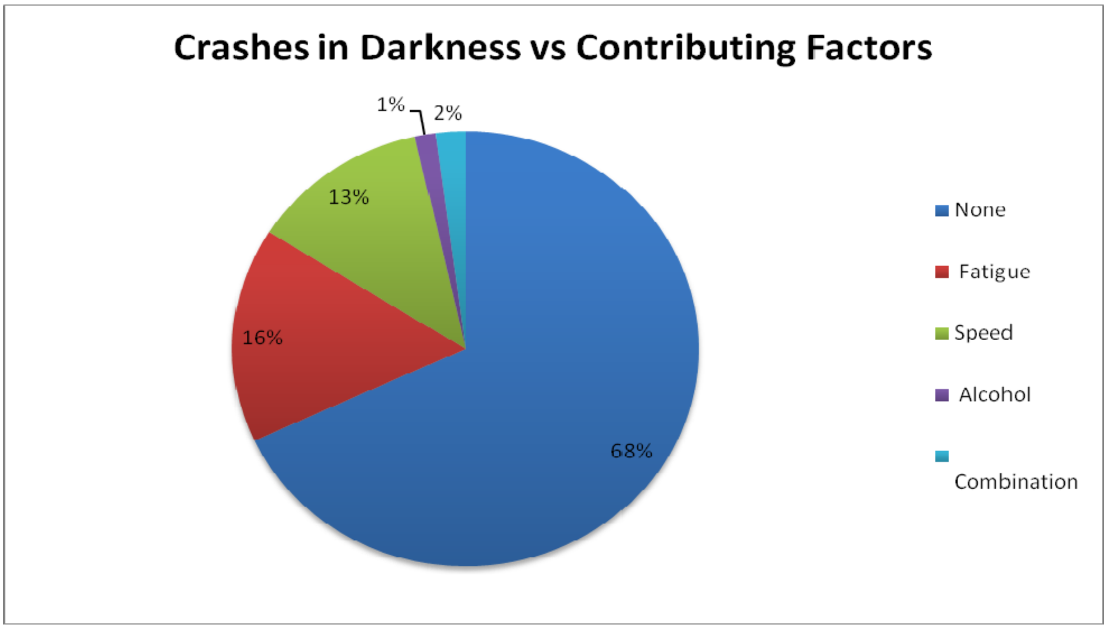

Figure 35: M1 Study - Night Time Crashes and Contributing Factors

Is poor visibility and the lack of street lighting a major contributor to driver error? And the crashes recorded on the M1? This was determined by calculating the number of crashes that occurred on exit and entry ramps with and without streetlight. Figure 36 shows that lighting was present on entry ramps when 49 of the 59 crashes occurred where as the majority of night time crashes on exit ramps occurred on ramps with no street lighting. The results indicated that street lighting provided on exit ramps has a large safety benefit with a 54% reduction of accidents compared to unlit exit ramps, where as the provision of street lighting on entry ramps does not reduce the likelihood of an accident occurring. The results for crashes occurring on entry ramps is positively skewed towards entry ramps with lighting as from the sites selected more entry ramps in the study had street lighting then no street lighting, However taking average accidents per ramp with different lighting conditions produces 4 accidents per lit entry ramps compared to 3 accidents per unlit entry ramps.

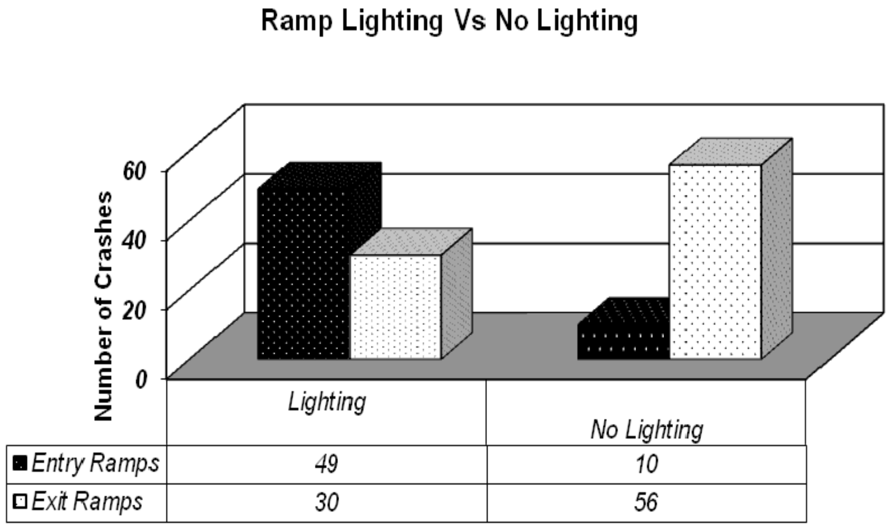

Figure 36: M1 Study - Night Time Crashes on Lit and Unlit Ramps

4.6 COST BENEFIT ANALYSIS

Taking the installation costs at $15,000 for a rural grade separated interchange and the maintenance cost $3500 annually and running cost $365 a year, a single street light will cost $18,865, in the first year and $3,865 every year its in service. The results have indicated that the biggest reduction in night accidents occurs on lit exit ramps, the average number of street lights installed on lit exit ramps on the M1 is 6 using this figure the total cost of providing street lighting on a exit ramp would be $113,190 in the first year and cost $23,190 to run and maintain the lights a year. However if the number of lights was reduced to be in accordance with AS/NZS 1158 2010 only 3 lights would be required costing $56,595 to install and $11,595 to maintain and run annually. The crash type that has seen a reduction in occurrence on lit exit ramps is run-off the road type crashes, according to the willingness to pay approach (Section 2.7) the cost of run-off the road type crashes is $153,000. If street lighting was provided on the 15 exit ramps selected in this study on the M1 in accordance to AS/NZS 1158

2010, then a total of 3 lights would be used to light the diverge of each exit ramp giving a total of 45 street lights at an annual running and maintenance cost of $173,925 or an annual cost of $11,595 per exit ramp.

A cost benefit analysis was conducted using the 18-year crash history of the selected exit ramps in this study. Over the 18 years there was a difference of 5 run-off road type crashes on lit and unlit exit ramps, giving a 0.277 reduction in run-off road type crashes on lit ramps over 18 years. Using 25 years for the cost benefit analysis a reduction of 7 crashes per lit ramp would occur of 25 years, a cost saving of $1, 062, 500 over 25 years based run-off crash costs estimated at $153, 000/crash. The cost of 3 street lights on an exit ramp would be $334, 875 over 25 years, giving a cost benefit value of 3.2. Calculations for the cost benefit analysis are shown in Appendix D.

Currently 41 lights in total are provided on exit ramps but only on 7 of the 15 exit ramps, so for a similar cost street lighting could be spread out evenly reducing the risks of accidents on all interchange exit ramps. Of course this is not practical for the M1 as the lights have been installed for many years, but for future projects lighting diverge areas in accordance to AS/NZS 1158 2010, may be a cost effective method to reduce the potential for run-off the road type crashes that are estimated to cost $153,000.

4.7 RESULTS SUMMARY

The key statistics from the results and analysis detailed above, which will contribute to the observations and recommendations made by this research area as follows;

- 66% of all accidents occur during the day.
- There is a 50% split of accidents on exit and entry ramps
- Exit ramps have the most crashes at night with 32% of the crashes on exit ramps occurring at night.
- 53% of accidents on exit ramps are run-off type crashes
- 53% of accidents on entry ramps are run-off type crashes
- A comparison of day and night crashes on exit ramps show that Hit object crashes are higher at night time compared to the day.

- There was an overall reduction in run-off type crashes on lit exit ramps compared to unlit exit ramps with 22 and 27 accidents occurring respectively.
- A comparison of day and night time crashes on entry ramps show similar crash types occur during the day and night
- 61% of accidents at night occurred in fine/dry conditions, 32% occurred in rain affected conditions
- 68% of accidents at night occurred with no contributing factors, fatigue was a contributing factor in 16% of the accidents.
- 30 accidents occurred on lit exit ramps compared to 56 on unlit exit ramps
- 49 accidents occurred on lit entry ramps compared to 10 on unlit entry ramps, due to the number of sites with and without lights the results showed that on average 4 accidents occur on lit entry ramps compared to 3 on unlit entry ramps.
- A single street light cost $3,865 to run and maintain annually on the M1
- The most common occurring crash on exit and entry ramps is run-off the road type crashes at an estimated cost of $153,000 per crash.
- Installation of street lighting on exit ramps as a safety measure has a cost benefit of 3.2.

5. RECOMMENDATIONS

This report will not recommend any amendments to current standards. It will make some recommendations for the provision of street lighting on interchange exit and entry ramps and it will also make some recommendations for where further research is required. Areas of further research are discussed in the next section. Recommendations for the use of street lighting as a safety measure to reduce night time accidents are shown below.

- Lit exit ramps have resulted in a reduction in accidents when compared to similar unlit exit ramps selected in the study. It is recommended that street lighting on exit ramps be considered for future projects as a safety measure for reducing night time crashes
- Night time crashes occur regardless of the provision of lighting or not on interchange entry ramps; with minimal reductions in accident rates the safety benefit of street lighting is questionable. It is recommended that lighting of interchange entry ramp merge areas for future projects be critically reviewed and omitted from designs if no safety benefit is expected.
- It is recommended that Figure 1: AS/NZS 1158.1 Typical Lighting Design Area for Diverge and Converging Locations, be revised to reflect the correct design method for exit ramps used in NSW as illustrated in Figure 6. The desirable length for the a vehicle to perform a diverge manoeuvre between the start of the exit ramp and the gore area is 235m, refereeing to VicRoads policy for lighting interchange ramp diverge and merge areas, it states any resultant gap in ramp lighting less than 300m is to be lit. Adopting this it is recommended that additional lights be added to AS/NZS 1158.1 Typical lighting design area for diverge locations.
- Another recommendation is that lighting on exit ramps be provide in accordance to AS/NZS 1158.1.1 2005, with 3 lights provided one at the start of the diverge area and two lights at the gore area, with further delineation be provided by Retro-reflective raised pavement markers (RRPM's) to improve the visual cues to the driver, whilst minimising the number of street lights provided. Green RRPM's could be adopted to further highlight to the driver there is a change in conditions with an exit ramp being present. Using green RRPM's as opposed to the generic white RRPM's further enhances a change to the driver. Main Roads Queensland currently practices the use of green RRPM's in diverge areas.

6. AREAS OF FURTHER RESEARCH

There are a number of areas and directions that can be followed on from the findings outlined in this research. These include:

- Traffic volume analysis on exit and entry ramps to get a true understanding of the crash rate compared to AADT. The study showed high rates of crashes occurring during the day compared to the crashes at night time, if AADT was considered on each ramp a percentage of crashes to vehicles at night could have been calculated to determine if night time crashes on entry and exit ramps are a significant concern or if daylight crashes are more significant.
- The number of street lights required on exit ramps to achieve maximum safety whilst optimising installation and maintenance costs.
- The effectiveness of using green RRPM's in the diverge area as adopted by Main Roads Queensland compared to the generic and widely adopted treatment of white RRPM's. Highlighting the diverge area to the driver using different coloured RRPM's that are only used on diverge lanes would alert the driver of a change ahead and elevate the need for a high number of street lights, which are more expensive and acts as an object that drivers can potentially hit hence the need for safety barrier protection.
- Before and after studies of crash records of interchanges where lighting has been retrofitted to ascertain the effect of the introduction of street lighting.
- The impact of increased lengths of merge and diverge areas in lit and unlit areas, it was noted in this research that the sites selected had varying deceleration and acceleration lane lengths.

7. CONCLUSION

This report has not recommended any amendments to the standards that govern street lighting on exit and entry ramps. The current research has shown there is a safety benefit of lighting interchange exit ramps, but minimal benefit in lighting entry ramps. The M1 study of 9 interchanges, involving 15 entry and 15 exit ramps showed a 50% split of accidents occurring on exit and entry ramps, however the reduction in night time accidents was more significant on exit ramps than on entry ramps. In general other factors contribute to night time crashes particular fatigue and wet road conditions, however majority of crashes recorded occurred with no contributing factors indicating driver error is a major factor.

The report identified that the type of crashes occurring on lit and unlit exit ramps at night time gives mixed results in determining if there is a safety benefit in lighting interchange ramps. Lit exit ramps showed a reduction in run-off type crashes compared to unlit exit ramps but there was an increase in hit object crashes, indicating that although street lighting was present drivers failed to pick up objects on the road. However comparing the total number of crashes on lit and unlit exit ramps there were 26 fewer crashes on lit exit ramps, suggesting street lighting has a positive safety benefit when used on interchange exit ramps. Further, the severity of crashes on lit exit ramps was significantly lower than on un-lit ramps. Specifically, there was a 200% decrease in fatality accidents and a 52% decrease in injury accidents on lit exit ramps.

The preliminary results suggest that the safety benefit from street lighting for interchange entry ramps and providing street lighting in the merge area was minimal. When comparing the number of crashes occurring on lit and unlit entry ramps on average 1 more crash was occurring per lit entry ramp then unlit entry. Further investigation into entry ramps is warranted to explore the preliminary results and to determine if there is a safety benefit of lighting these areas.

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APPENDIX A– PROJECT SPECIFICATION

University of Southern Queensland
Faculty of Health, Engineering and Sciences
ENG4111 Research Project Part 1
PROJECT SPECIFICATION

Full Name: Scott Power

Student Number: 0050086937

Proposed Topic: Does Street lighting on grade separated interchange ramps have an increase in safety benefits.

Sponsorship: Roads and Maritime Services, NSW

Supervisor: Trevor Drysdale

Industry Supervisor: Justin Drinkwater

Project Aim: To investigate the safety and cost implications of the lighting standards for interchange ramps.

Program: Issue A – 19 March, 2014

1. Review literature related to provision of street lighting on entry and exit ramps at grade separated interchanges, and in particular the areas of
    - Provision for street lighting on entry and exit ramps for grade separated interchanges within Australia and around the world
    - Review of the Australian standards.
2. Identification of specific grade separated interchange entry and exit ramps on the M1 that comply with the street lighting standard and that do not comply with street lighting standards.
3. Design a methodology which allows collection of data at various entry and exit ramps at grade separated interchanges
4. Compare the crash data at entry and exit ramps on grade separated interchanges that have the same speed and AADT, but have different street lighting configurations.
5. Analyse the crash data and determine if the street lighting provided or not provided increases or decreases the crash rate in a predictable fashion.
6. Conduct a cost benefit analysis which considers street lighting installation costs, maintenance costs, running costs, protection costs, and crash rates on entry and exit ramps.
7. Recommend on whether or not changes are required to existing design standards for street lighting on entry and exit ramps.
8. Report research findings in the required oral and written formats.

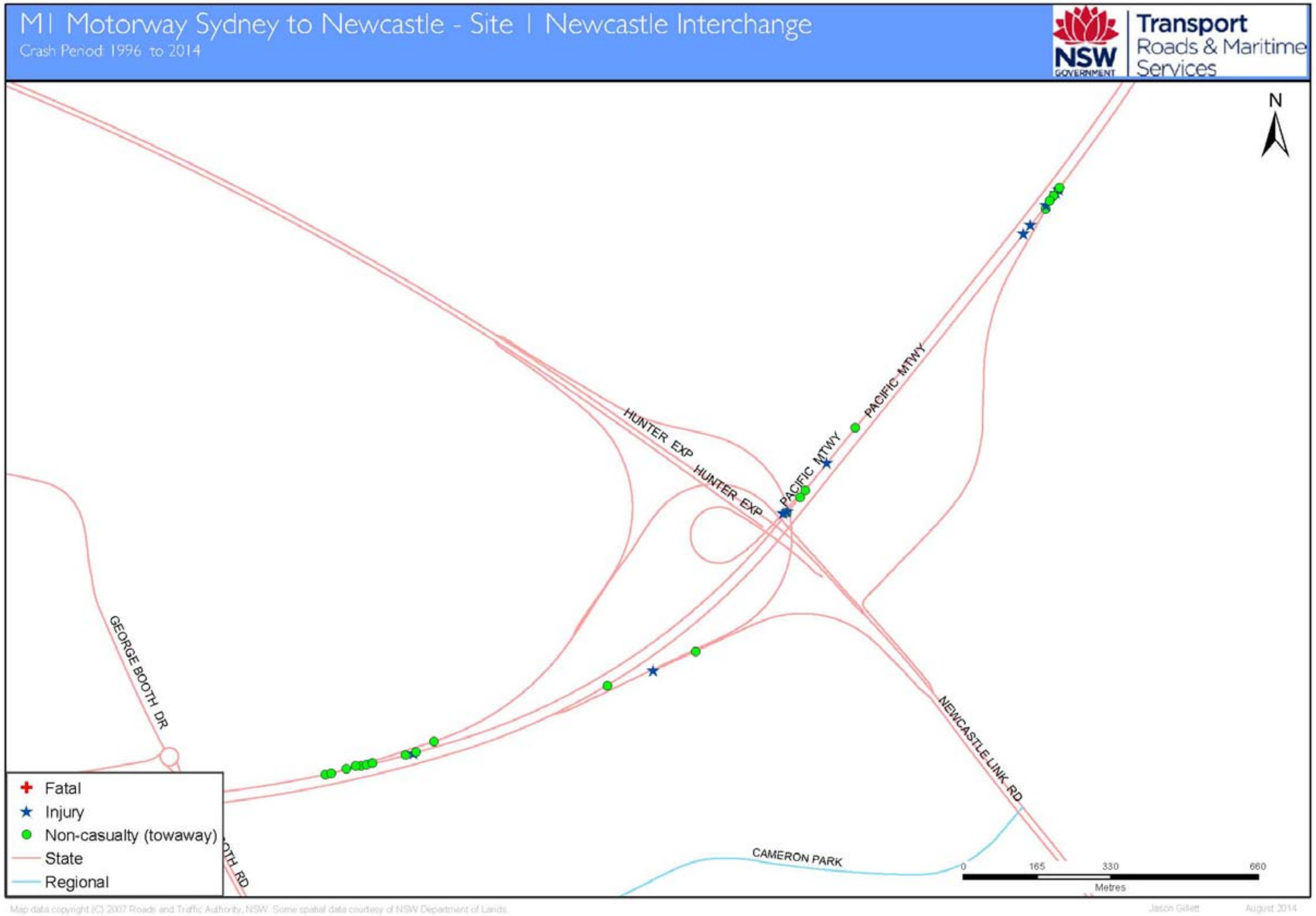
Agreed:

Signature ______________ **19/03/14**
Supervisor: Trevor Drysdale

Signature ______________ **19/03/14**
Industry Supervisor: Justin Drinkwater

Signature SPower **19/03/14**
Student: Scott Power

APPENDIX B – SITE CRASH MAPS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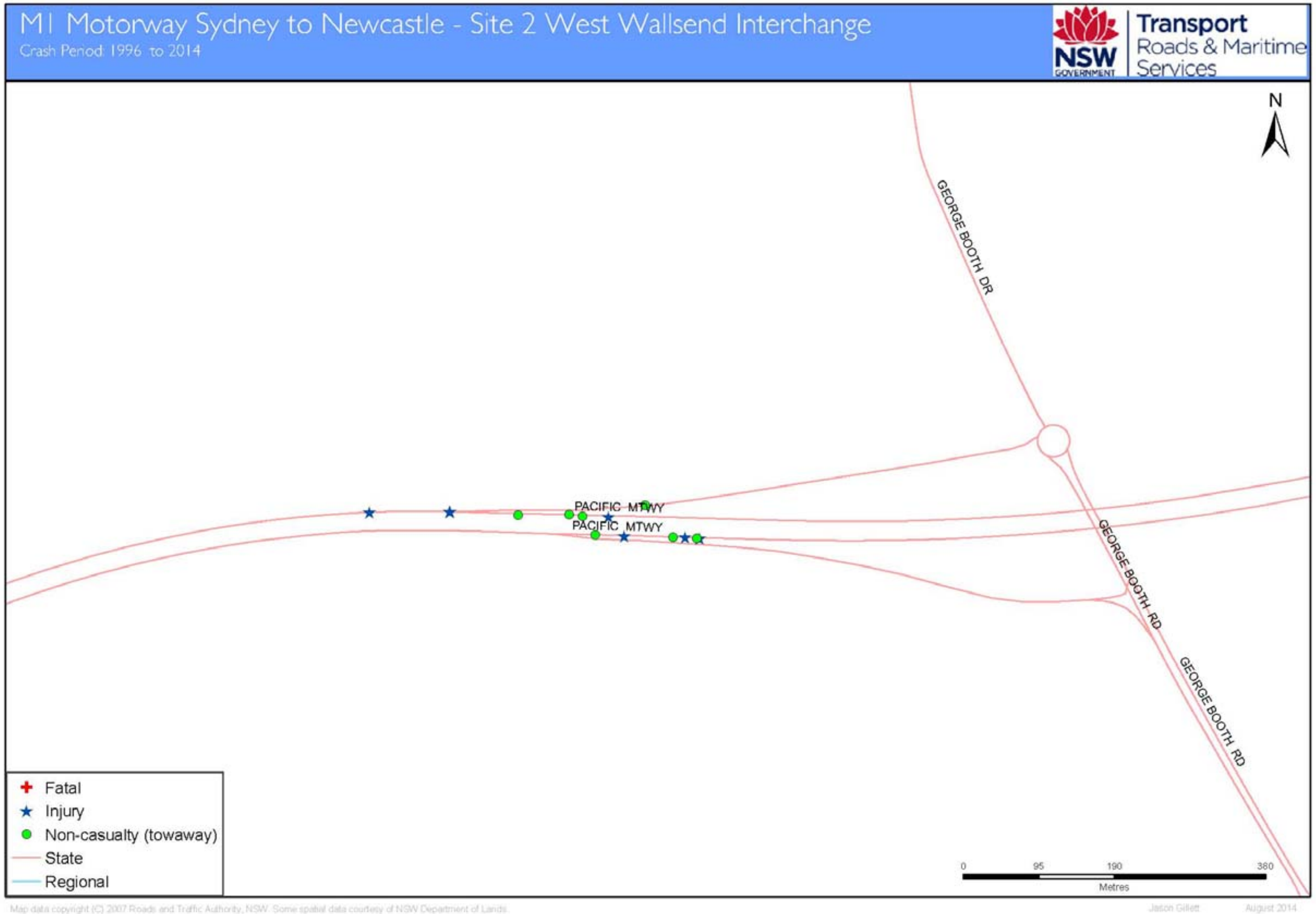
Crash Period: 1996 to 2014
Transport
Roads & Maritime
Services
NSW GOVERNMENT
N
HUNTER EXP
HUNTER EXP
PACIFIC MTWY
PACIFIC MTWY
GEORGE BOOTH DR
NEWCASTLE LINK RD
CAMERON PARK
Fatal
Injury
Non-casualty (towaway)
State
Regional
0
165
330
660
Metres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NSW GOVERNMENT
Transport
Roads & Maritime
Services
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PACIFIC MTWY
GEORGE BOOTH RD
GEORGE BOOTH RD
Fatal
Injury
Non-casualty (towaway)
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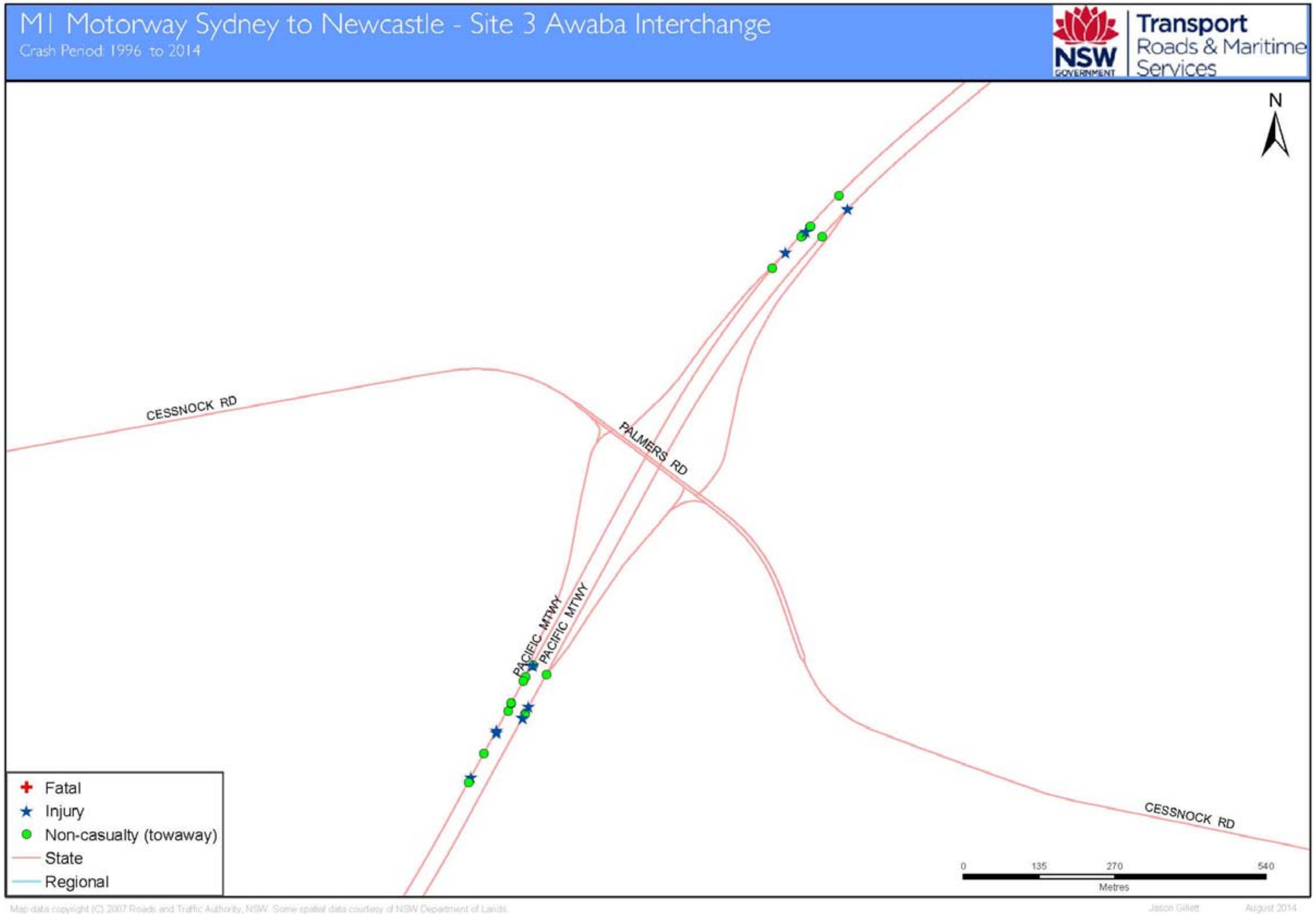
Map data copyright (C) 2007 Roads and Traffic Authority, NSW. Some spatial data courtesy of NSW Department of Lands.
Jason Gillett
August 2014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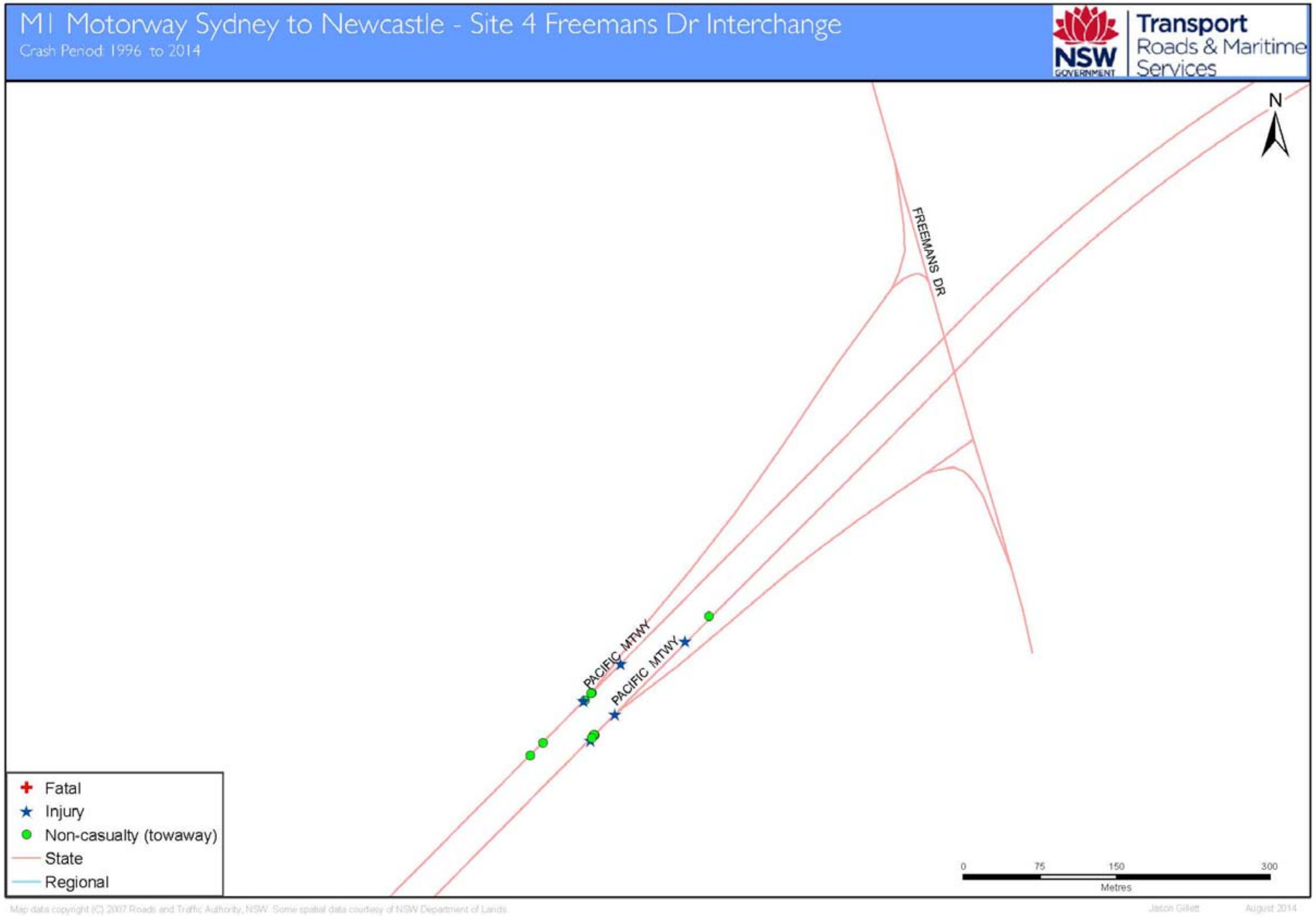
NSW GOVERNMENT
Transport Roads & Maritime Services
N
CESSNOCK RD
PALMERS RD
PACIFIC MTWY
PACIFIC MTWY
CESSNOCK RD
Fatal
Injury
Non-casualty (towaway)
State
Regional
0
135
270
540
Metres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Transport Roads & Maritime Services
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FREEMANS DR
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PACIFIC MTWY
Fatal
Injury
Non-casualty (towaway)
State
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75
150
300
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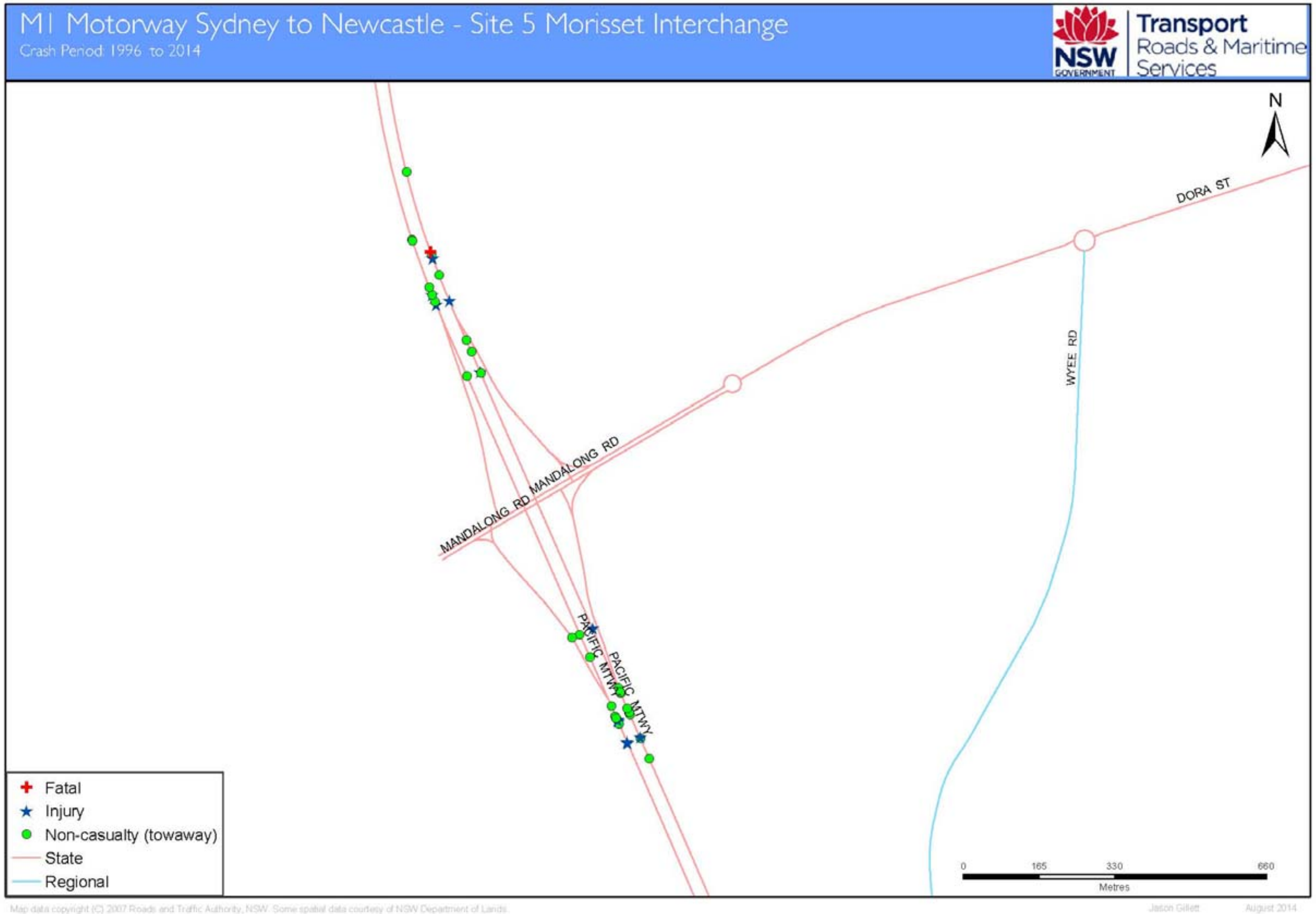
Map data copyright (C) 2007 Roads and Traffic Authority, NSW. Some spatial data courtesy of NSW Department of Lands.
Jason Gillett
August 2014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DORA ST
WYEE RD
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PACIFIC MTWY
PACIFIC MTWY
Fatal
Injury
Non-casualty (towaway)
State
Regional
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165
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660
Metres
Map data copyright (C) 2007 Roads and Traffic Authority, NSW. Some spatial data courtesy of NSW Department of Lands.
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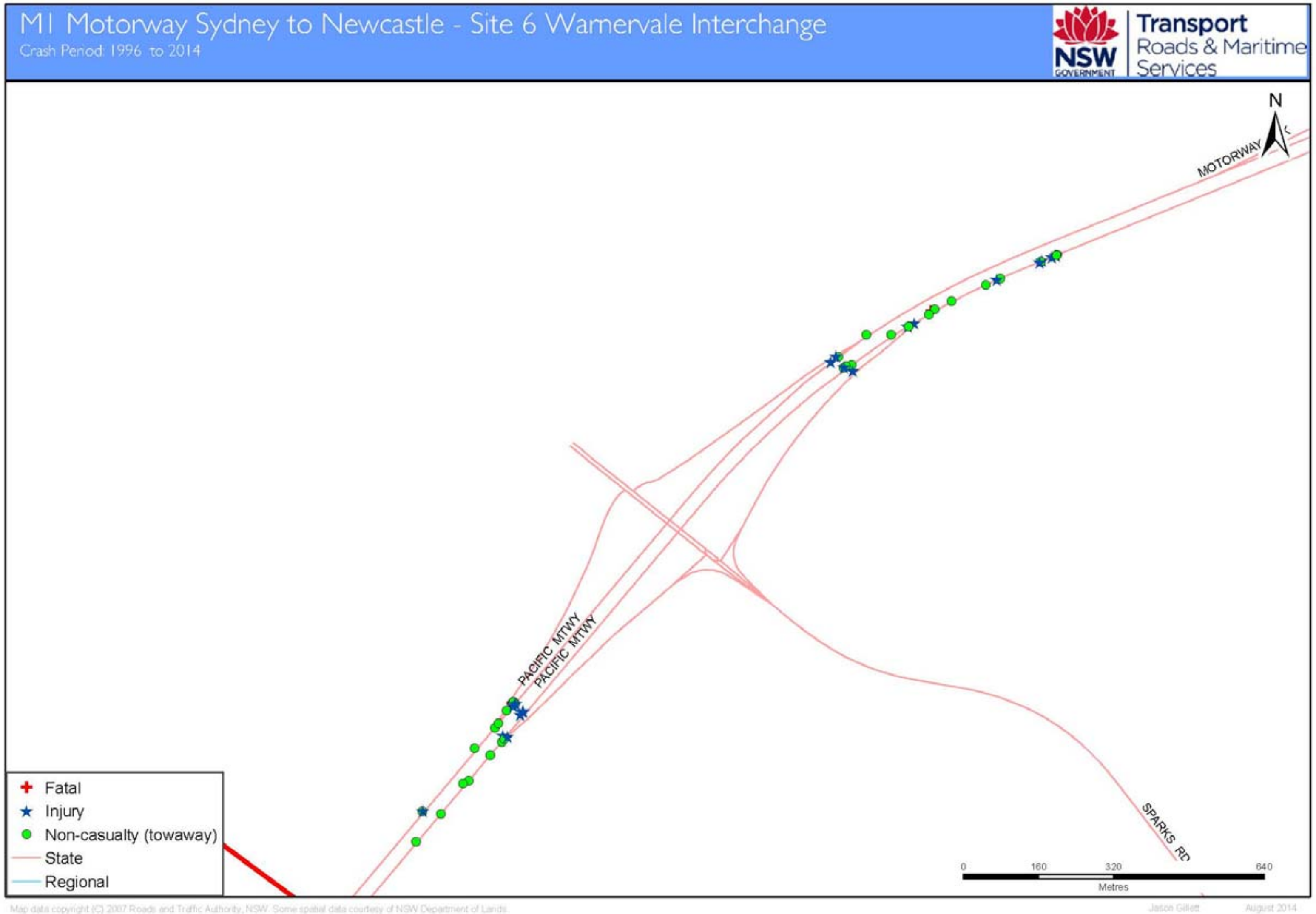
August 2014


M1 Motorway Sydney to Newcastle - Site 6 Warnervale Interchange
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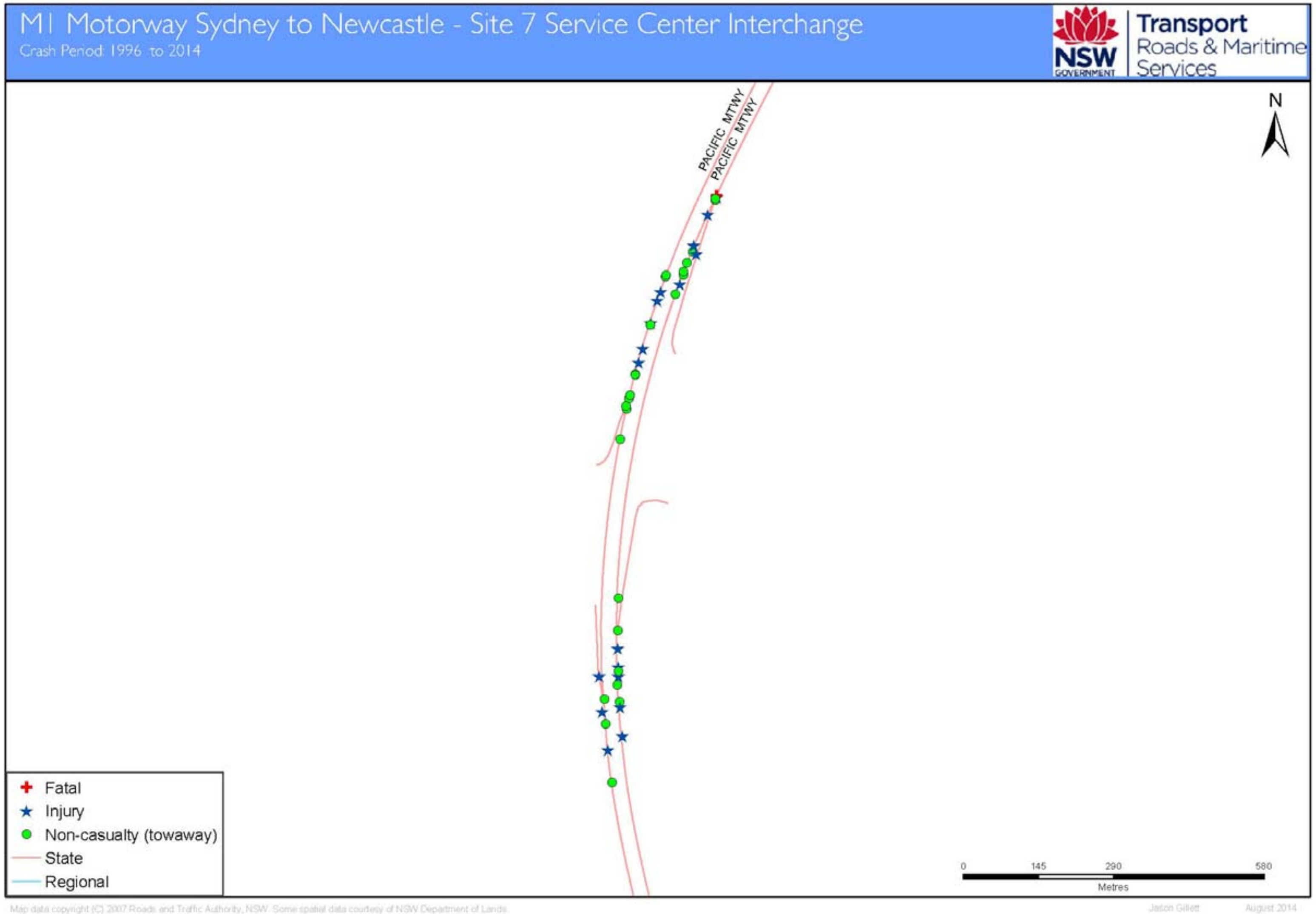
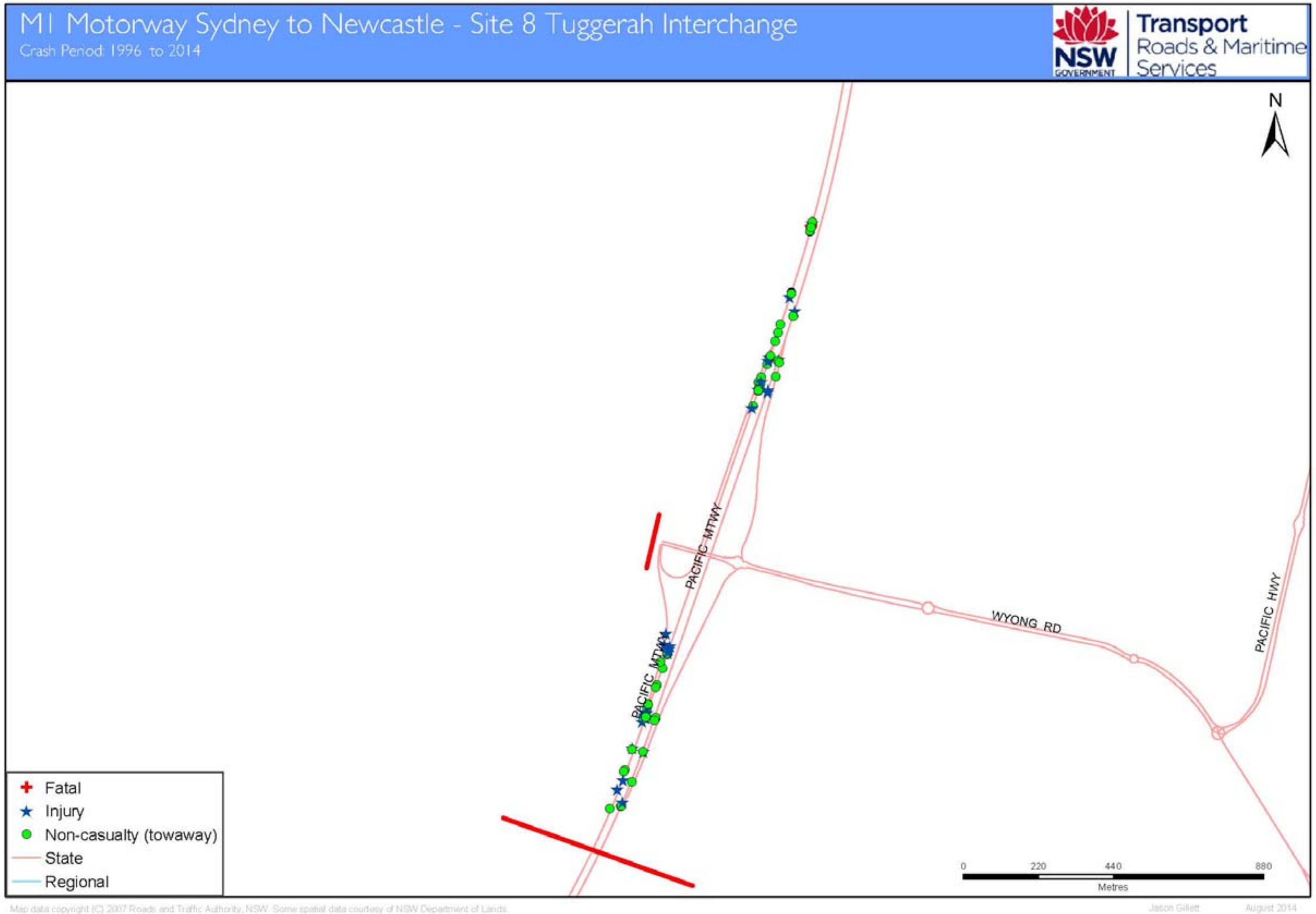
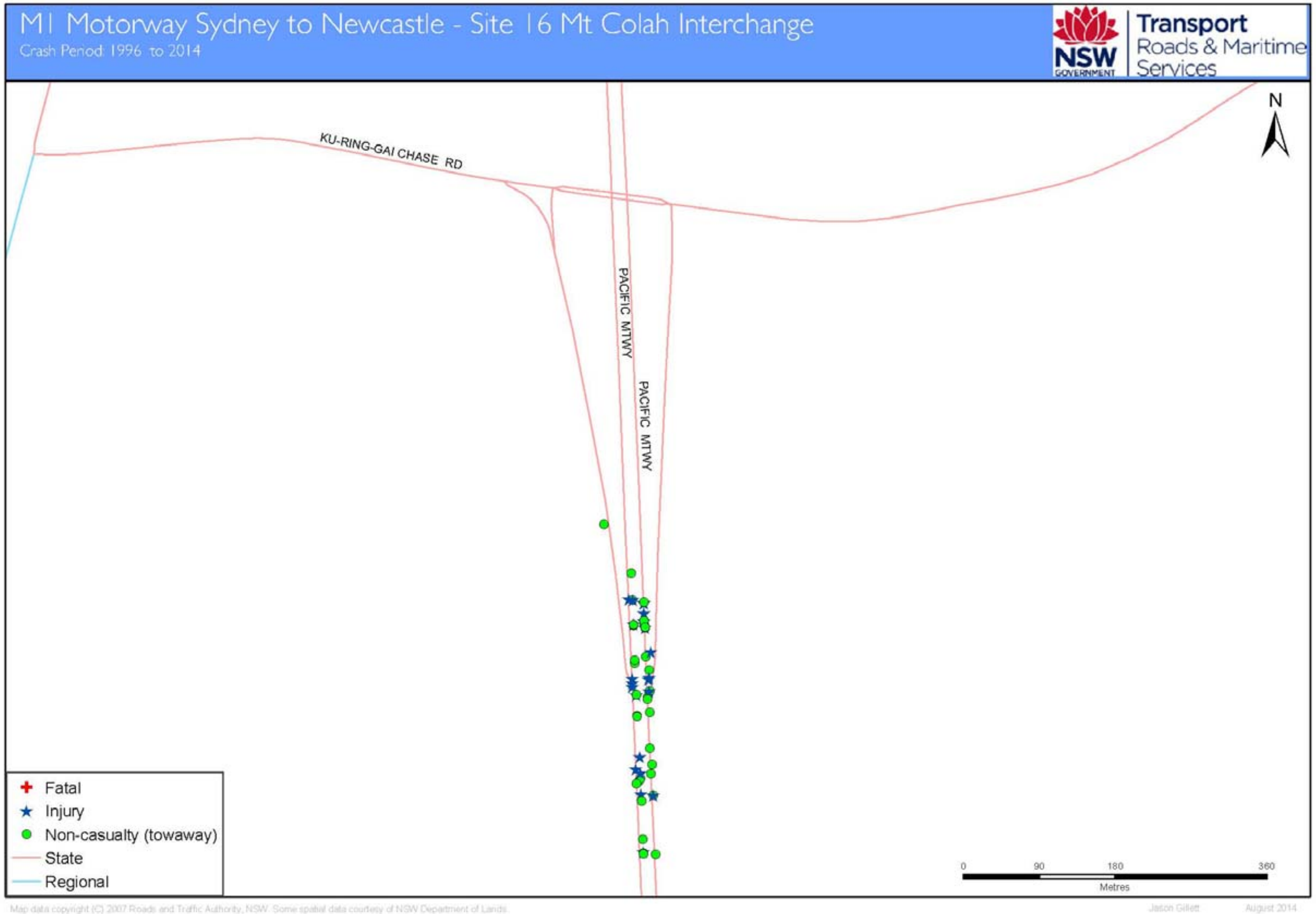
NSW GOVERNMENT
Transport Roads & Maritime Services
N
MOTORWAY
PACIFIC MTWY
PACIFIC MTWY
SPARKS RD
Fatal
Injury
Non-casualty (towaway)
State
Regional
0
160
320
640
Metres
Map data copyright (C) 2007 Roads and Traffic Authority, NSW. Some spatial data courtesy of NSW Department of Lands.
Jason Gillett
August 2014


M1 Motorway Sydney to Newcastle - Site 7 Service Center Interchange
Crash Period: 1996 to 2014
Transport
Roads & Maritime
Services
NSW
GOVERNMENT
N
PACIFIC MTWY
PACIFIC MTWY
Fatal
Injury
Non-casualty (towaway)
State
Regional
0
145
290
580
Metres
Map data copyright (C) 2007 Roads and Traffic Authority, NSW. Some spatial data courtesy of NSW Department of Lands.
Jason Gillett
August 2014


M1 Motorway Sydney to Newcastle - Site 8 Tuggerah Interchange
Crash Period: 1996 to 2014
NSW GOVERNMENT
Transport Roads & Maritime Services
N
PACIFIC MTWY
PACIFIC MTWY
WYONG RD
PACIFIC HWY
Fatal
Injury
Non-casualty (towaway)
State
Regional
0
220
440
880
Metres


M1 Motorway Sydney to Newcastle - Site 16 Mt Colah Interchange
Crash Period: 1996 to 2014
NSW GOVERNMENT
Transport
Roads & Maritime
Services
N
KU-RING-GAI CHASE RD
PACIFIC MTWY
PACIFIC MTWY
Fatal
Injury
Non-casualty (towaway)
State
Regional
0
90
180
360
Metres

APPENDIX C – DETAILED CRASH DATA REPORTS

Newcastle Interchange								
	Date	**Time**	**Natural Light**	**Weather Conditions**	**Road Alignment**	**Degree of Crash**	**Type of Crash**	**Contributing Factors**
Northbound Exit	06/11/1996	23:30	Darkness	Fine/Dry	Straight	Towaway	Veered left off road into object	No
	12/12/1997	16:15	Daylight	Fine/Dry	Curve	Injury	Veered right off road	No
	13/09/1998	09:15	Daylight	Fine/Dry	Straight	Injury	On road out of control	Fatigue
	13/12/2000	06:00	Dawn	Fine/Dry	Straight	Towaway	Veered left off road into parked car	Fatigue
	31/08/2001	14:15	Daylight	Fine/Dry	Curve	Injury	Veered left off road into object	Fatigue
	06/04/2002	15:00	Daylight	Fine/Dry	Straight	Towaway	Hit object on road	No
	08/08/2005	10:25	Daylight	Fine/Dry	Curve	Towaway	Veered left off road into object	Speed
	10/11/2005	03:45	Darkness	Fine/Dry	Straight	Towaway	Veered left off road into trees	Fatigue
	23/11/2008	12:30	Daylight	Raining	Straight	Injury	Lane Sideswipe	No
	24/06/2009	07:15	Daylight	Fine/Dry	Curve	Towaway	Veered left off road into object	Speed
	26/09/2009	00:30	Darkness	Fine/Dry	Curve	Towaway	Veered left off road into object	Speed
	10/11/2009	13:50	Daylight	Fine/Dry	Curve	Towaway	Veered left off road into object	Speed
	09/02/2010	13:50	Daylight	Overcast/Wet	Straight	Towaway	Hit car changing into left lane	No
	16/06/2010	01:40	Darkness	Fine/Dry	Straight	Towaway	Veered left off road into trees	Fatigue
	13/10/2010	04:30	Darkness	Fine/Dry	Straight	Injury	Veered right off road into trees	No
	13/10/2010	16:41	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	14/12/2010	06:30	Dawn	Fine/Dry	Curve	Towaway	Veered left off road into object	Speed
	04/03/2011	01:00	Darkness	Fine/Dry	Curve	Towaway	Veered right off road into trees	No
	15/11/2012	22:30	Darkness	Fine/Dry	Curve	Injury	Veered right off road	Speed
Northbound Entry	21/05/1999	19:10	Darkness	Fine/Dry	Straight	Towaway	Veered right off road	No
	21/04/2002	17:10	Dusk	Raining	Curve	Injury	Out of control on bend	Speed
	12/07/2002	07:40	Daylight	Fine/Dry	Curve	Towaway	Veered left off road into utility pole	Speed
	26/11/2002	15:00	Daylight	Overcast/Dry	Straight	Injury	Hit vehicle changing into right lane	No

	18/08/2006	06:05	Dawn	Fine/Dry	Curve	Towaway	Veered right off road into object	No
	07/12/2006	12:00	Daylight	Fine/Dry	Straight	Injury	Veered right off road	No
	12/04/2009	16:00	Daylight	Overcast/Dry	Curve	Injury	Veered right off road into object	Speed
	05/05/2009	09:00	Daylight	Raining	Curve	Towaway	Veered left off road into utility pole	Speed
	30/01/2010	07:30	Daylight	Raining	Straight	Towaway	Veered right off road	No
	31/05/2011	06:45	Daylight	Raining	Straight	Towaway	Hit vehicle changing into right lane	No
	30/03/2012	06:30	Dawn	Fine/Dry	Straight	Injury	Hit object on road	No
	04/11/2012	11:00	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	Speed
Southbound Exit	29/05/2002	13:30	Daylight	Fine/Dry	Straight	Towaway	Hit vehicle changing into right lane	No
	21/02/2003	08:40	Daylight	Raining	Straight	Injury	Veered left off road into object	No
	24/11/2003	04:30	Darkness	Raining	Straight	Towaway	Veered right off road into trees	No
	16/01/2004	00:50	Darkness	Fine/Dry	Straight	Injury	Veered left off road into object	No
	11/11/2005	04:45	Dawn	Fine/Dry	Straight	Towaway	Hit object on road, multiple vehicles	No
	22/12/2007	08:40	Daylight	Raining	Straight	Towaway	Veered right off road into trees	Fatigue
	22/04/2008	15:16	Daylight	Raining	Straight	Injury	Veered left off road into traffic island	Fatigue
	05/09/2008	21:00	Darkness	Raining	Straight	Towaway	Veered left off road into trees	Fatigue
	30/10/2009	20:55	Darkness	Fine/Dry	Straight	Injury	Rear end collision	No
	16/02/2010	11:20	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	12/12/2011	06:00	Dawn	Overcast/wet	Straight	Towaway	Veered left off road into trees	No
Southbound Entry	17/01/2004	21:00	Darkness	Fine/Dry	Curve	Towaway	Veered left off road into object	Speed
	12/09/2006	01:59	Darkness	Raining	Straight	Injury	Veered right off road into object	Speed
	26/10/2006	21:40	Darkness	Fine/Dry	Straight	Towaway	Veered left off road into trees	Alcohol

West Wallsend Interchange								
	Date	**Time**	**Natural Light**	**Weather Conditions**	**Road Alignment**	**Degree of Crash**	**Type of Crash**	**Contributing Factors**
Northbound Exit	18/05/1997	16:25	Daylight	Raining	Straight	Towaway	Veered left off road into traffic island	No
	10/04/2001	09:45	Daylight	Raining	Straight	Towaway	Veered left off road into object	No
	04/02/2002	08:15	Daylight	Raining	Straight	Injury	Veered right off road	No
	09/01/2008	16:30	Daylight	Fine/Dry	Curve	Towaway	Veered left into traffic island	No
	31/05/2010	10:25	Daylight	Raining	Straight	Injury	Veered right off road	No
	31/01/2011	07:20	Dawn	Fine/Dry	Straight	Injury	Veered right off road into trees	Fatigue
	01/07/2011	18:30	Dusk	Fine/Dry	Straight	Towaway	Veered right off road into trees	Speed and Fatigue
	25/03/2012	22:50	Darkness	Fine/Dry	Straight	Injury	Veered right off road into trees	No
Southbound Entry	18/12/1997	17:50	Dusk	Raining	Straight	Injury	Veered right off road into object	No
	23/08/1998	17:30	Dusk	Fine/Dry	Straight	Towaway	Veered right off road into object	No
	23/05/2000	08:25	Daylight	Fine/Dry	Curve	Towaway	Veered right off road into embankment	Speed and Fatigue
	21/02/2006	08:00	Daylight	Raining	Straight	Injury	Veered right into traffic island	No
	23/02/2006	08:55	Daylight	Raining	Straight	Towaway	Veered right off road into trees	No
	05/12/2009	14:00	Daylight	Fine/Dry	Straight	Towaway	Veered left off road into object	No
	06/01/2012	23:40	Darkness	Fine/Dry	Straight	Injury	Veered right off road into embankment	Fatigue
	27/09/2012	14:43	Daylight	Fine/Dry	Straight	Injury	Hit vehicle changing into left lane	No

Awaba Interchange								
	Date	**Time**	**Natural Light**	**Weather Conditions**	**Road Alignment**	**Degree of Crash**	**Type of Crash**	**Contributing Factors**
Northbound Exit	08/09/2001	00:15	Darkness	Raining	Straight	Towaway	Hit non fixed object on road	No
	08/09/2001	00:15	Darkness	Raining	Straight	Injury	Rear end Collision	No
	27/10/2004	15:00	Daylight	Fine/Dry	Straight	Injury	Veered left off road into trees	No
	11/02/2007	16:00	Daylight	Fine/Dry	Straight	Towaway	Veered right off road into trees	Fatigue
	26/10/2007	13:00	Daylight	Raining	Straight	Towaway	Veered right off road into trees	No
	19/11/2008	14:00	Daylight	Fine/Dry	Straight	Towaway	Veered right off road into fence	No
	26/10/2008	12:25	Daylight	Fine/Dry	Straight	Injury	Veered left off road	No
	24/09/2009	11:29	Daylight	Fine/Dry	Straight	Injury	On road out of control	No
	03/06/2010	18:30	Darkness	Raining	Straight	Towaway	Veered left off road into trees	No
	03/06/2010	19:15	Darkness	Raining	Straight	Towaway	Hit broken down car	No
	22/12/2011	15:50	Daylight	Raining	Straight	Towaway	Veered right of road into trees	Fatigue
	23/12/2011	14:45	Daylight	Fine/Wet	Straight	Towaway	Veered left off road into fence	No
	02/02/2013	12:40	Daylight	Raining	Straight	Injury	Veered left off road	No
Northbound Entry	21/12/1997	18:35	Dusk	Raining	Straight	Towaway	Veered right off road into trees	No
	14/04/1998	23:00	Darkness	Fine/Dry	Straight	Towaway	Rear end Collision	No
	12/04/2000	08:05	Daylight	Overcast/Dry	Curve	Towaway	Veered left off road into fence	Speed
	03/07/2000	01:00	Darkness	Raining	Straight	Towaway	Lane side swipe	Speed
	29/04/2002	05:50	Dawn	Raining	Straight	Injury	Veered right off road into embankment	Fatigue
	27/11/2004	18:23	Daylight	Fine/Dry	Straight	Towaway	Veered right off road into trees	No
	20/04/2008	08:30	Daylight	Raining	Straight	Towaway	Veered left off road into trees	No
	22/04/2008	16:55	Dusk	Raining	Curve	Towaway	Veered right off road into trees	Speed
	10/06/2009	00:50	Darkness	Fine/Dry	Curve	Towaway	Veered right off road into traffic island	Fatigue
	17/08/2009	16:05	Daylight	Fine/Dry	Straight	Injury	Collision changing into right lane	No
Southbound	28/02/2002	06:10	Dawn	Raining	Straight	Towaway	Veered left off road into trees	No

Exit	29/04/2002	09:32	Daylight	Raining	Straight	Injury	Veered left off road into trees	No
	14/10/2012	00:30	Darkness	Raining	Straight	Injury	Veered left off road into trees	Fatigue
Southbound Entry	21/03/2000	15:50	Daylight	Raining	Straight	Injury	Veered right off road into trees	No
	17/03/2003	06:00	Darkness	Fine/Dry	Straight	Injury	Veered right off road	Fatigue
	20/03/2007	17:00	Daylight	Raining	Straight	Towaway	Veered left off road into embankment	No
	19/11/2010	06:15	Daylight	Overcast/Dry	Straight	Injury	Veered right off road into bridge	No
	13/05/2011	18:20	Darkness	Fine/Dry	Straight	Towaway	Lane side swipe	Speed
	02/10/2011	11:15	Daylight	Raining	Straight	Towaway	Veered left off road into trees	No

Freemans Dr Interchange								
	Date	**Time**	**Natural Light**	**Weather Conditions**	**Road Alignment**	**Degree of Crash**	**Type of Crash**	**Contributing Factors**
Northbound Exit	19/11/2001	17:00	Daylight	Raining	Straight	Towaway	Veered right off road into trees	No
	12/06/2003	08:00	Daylight	Fog/Dry	Straight	Towaway	Rear end Collision	No
	24/11/2003	09:14	Daylight	Overcast/Dry	Straight	Towaway	Veered right off road into trees	No
	23/11/2006	11:20	Daylight	Fine/Dry	Straight	Injury	On road out of control	Fatigue
	07/04/2011	19:53	Darkness	Fine/Dry	Straight	Towaway	Hit vehicle changing lanes to left	No
	27/11/2013	06:05	Dawn	Fine/Dry	Straight	Towaway	Veered right off road into trees	Fatigue
Southbound Entry	06/05/1999	01:40	Darkness	Raining	Straight	Towaway	Veered right off road into body of water	No
	09/12/2004	15:22	Daylight	Overcast/Dry	Straight	Injury	Veered left off road into trees	No
	16/11/2005	10:00	Daylight	Overcast/Dry	Straight	Towaway	Veered right off road into object	Fatigue
	29/03/2008	06:50	Dawn	Fine/Dry	Straight	Towaway	Veered right off road into trees	No
	20/11/2009	15:00	Daylight	Fine/Dry	Straight	Injury	Hit vehicle merging right	No
	10/01/2012	14:00	Daylight	Fine/Dry	Straight	Towaway	Veered left into parked car	No
	26/01/2014	15:40	Daylight	Fine/Dry	Straight	Towaway	Veered right off road into trees	Fatigue and Speed

Morisset Interchange								
	Date	**Time**	**Natural Light**	**Weather Conditions**	**Road Alignment**	**Degree of Crash**	**Type of Crash**	**Contributing Factors**
Northbound Exit	14/08/1996	06:30	Dawn	Fine/Dry	Straight	Towaway	Veered left off road into object	No
	09/09/1997	16:45	Daylight	Fine/Dry	Straight	Towaway	Veered left off road into object	Fatigue
	11/12/1997	15:05	Daylight	Fine/Dry	Straight	-	Veered left off road into sign post	No
	24/04/1999	08:55	Daylight	Overcast/Dry	Straight	Towaway	Object stuck vehicle	No
	19/03/2000	04:00	Darkness	Overcast/Dry	Straight	Towaway	Veered right off road	Fatigue
	06/03/2001	16:30	Daylight	Raining	Straight	Injury	Veered right off road into trees	No
	27/02/2002	21:00	Darkness	Raining	Straight	Injury	Veered right off road into trees	No
	30/08/2002	19:15	Darkness	Fine/Dry	Straight	Injury	Veered left off road into sign post	Fatigue
	19/04/2008	17:10	Dusk	Overcast/Wet	Curve	Towaway	Veered right off road into object	Speed
	20/04/2010	10:27	Daylight	Fine/Dry	Straight	Injury	Hit object on road	Speed
	03/06/2013	04:25	Darkness	Fine/Dry	Straight	Injury	Veered right off road into trees	Fatigue
Northbound Entry	31/12/1995	10:30	Daylight	Fine/Dry	Straight	Injury	Veered right off road into trees	No
	20/03/2007	17:00	Daylight	Raining	Straight	Towaway	Hit vehicle changing into right lane	No
	11/12/2007	23:12	Darkness	Fine/Dry	Curve	Towaway	Hit object on road	No
	12/02/2008	12:25	Daylight	Fine/Dry	Straight	Towaway	Lane Sideswipe	No
	11/07/2009	12:00	Daylight	Overcast/Dry	Straight	Towaway	Veered right off road into trees	No
	04/02/2010	08:13	Daylight	Raining	Straight	Towaway	Veered right off road into trees	No
	14/06/2011	18:15	Darkness	Raining	Curve	Injury	Veered right off road into trees	Speed
	18/04/2012	05:50	Darkness	Raining	Straight	Towaway	Veered right off road into trees	No
	12/06/2012	14:41	Daylight	Raining	Straight	Towaway	Veered right off road	No
	02/12/2013	16:30	Daylight	Fine/Dry	Straight	Towaway	Veered right off road	Fatigue
Southbound Exit	08/03/2001	17:00	Dusk	Raining	Straight	Towaway	Veered right off road into trees	No
	09/03/2001	15:00	Daylight	Raining	Straight	Injury	Veered right off road into trees	No
	09/04/2001	02:00	Darkness	Fine/Dry	Straight	Fatality	Veered right off road into object	No
	19/04/2005	16:30	Daylight	Fine/Dry	Straight	Towaway	Veered right off road into trees	No
	24/02/2007	18:10	Daylight	Fine/Dry	Straight	Injury	Veered right off road into object	Fatigue
	16/09/2007	07:40	Daylight	Fine/Dry	Straight	Towaway	Hit vehicle performing U-turn	No
	24/01/2012	05:22	Dawn	Overcast/Wet	Straight	Towaway	Hit broken down vehicle	No

Southbound Entry	01/06/1996	17:00	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	08/03/1999	17:10	Daylight	Raining	Straight	Injury	Veered left off road into sign post	Fatigue
	01/10/2001	19:45	Darkness	Fine/Dry	Straight	Towaway	Veered right off road into trees	No
	25/05/2006	18:00	Dusk	Fine/Dry	Straight	Towaway	Rear end collision	No
	26/06/2008	07:30	Dawn	Fine/Dry	Straight	Towaway	Hit object on road	No
	17/03/2009	22:30	Darkness	Fine/Dry	Straight	Towaway	Veered right off road into trees	Fatigue
	22/01/2010	12:30	Daylight	Fine/Dry	Straight	Towaway	Veered left off road into utility pole	Fatigue
	09/06/2010	18:00	Darkness	Fine/Dry	Straight	Towaway	Hit vehicle performing U-turn	No
	14/03/2011	08:20	Daylight	Fine/Dry	Straight	Towaway	Hit vehicle changing into right lane	No
	22/08/2011	21:30	Darkness	Fine/Dry	Straight	Towaway	Veered right off road into trees	No
	13/10/2011	16:35	Daylight	Fine/Dry	Straight	Towaway	Hit vehicle performing U-turn	No
	04/01/2012	22:30	Darkness	Fine/Dry	Straight	Towaway	Hit kangaroo	No

Warnervale Interchange								
	Date	**Time**	**Natural Light**	**Weather Conditions**	**Road Alignment**	**Degree of Crash**	**Type of Crash**	**Contributing Factors**
Northbound Exit	30/01/1998	16:30	Daylight	Fine/Dry	Straight	Towaway	Hit vehicle in same direction	No
	31/07/1998	13:20	Daylight	Fine/Dry	Straight	Injury	Veered left off road into traffic island	Fatigue
	15/01/2000	10:10	Daylight	Raining	Straight	Towaway	Veered right off road	No
	18/07/2000	15:25	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	25/12/2001	17:30	Daylight	Fine/Dry	Curve	Towaway	Veered right off road into sign post	Fatigue
	28/02/2002	04:13	Darkness	Raining	Curve	Towaway	Veered right off road into trees	Speed
	28/01/2004	16:50	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	09/11/2004	14:00	Daylight	Raining	Curve	Injury	Rear end collision	No
	03/06/2005	21:30	Darkness	Fine/Dry	Straight	Fatality	Veered left off road into sign post	Fatigue
	30/10/2005	00:30	Darkness	Fine/Dry	Straight	Towaway	Veered left off road into object	No
	19/04/2008	05:03	Darkness	Raining	Straight	Towaway	Veered right off road into trees	Speed
	25/01/2009	15:00	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	09/08/2009	23:50	Darkness	Fine/Dry	Straight	Injury	Rear end collision	Fatigue
	18/09/2009	18:34	Darkness	Fine/Dry	Straight	Injury	Rear end collision	No
	10/10/2012	18:00	Daylight	Fine/Dry	Straight	Towaway	Veered right off road into embankment	No
	22/04/2013	17:15	Dusk	Fine/Dry	Straight	Injury	Veered left off road into object	No
Northbound Entry	13/09/2002	19:45	Darkness	Fine/Dry	Straight	Injury	Veered right off road	No
	16/06/2006	23:00	Darkness	Fine/Dry	Straight	Towaway	Hit vehicle changing into right lane	No
	29/11/2009	13:30	Daylight	Fine/Dry	Curve	Injury	Rear end collision	No
	09/10/2010	11:30	Daylight	Overcast/dry	Straight	Towaway	Hit vehicle changing into left lane	No
Southbound Exit	30/04/1996	20:25	Darkness	Overcast/dry	Straight	Injury	Hit vehicle performing U-turn	No
	19/01/1997	22:40	Darkness	Fine/Dry	Straight	Injury	Rear end collision	Alcohol
	19/03/1998	23:05	Darkness	Fine/Dry	Straight	Towaway	Lane sideswipe	Speed
	18/12/1998	10:55	Daylight	Fine/Dry	Straight	Towaway	Hit parked vehicle	No
	17/02/2002	00:40	Darkness	Raining	Curve	Towaway	Rear end collision	No
	25/03/2002	16:00	Daylight	Fine/Dry	Curve	Injury	Lane sideswipe	No
	17/04/2003	02:10	Darkness	Raining	Straight	Towaway	Lane sideswipe	No
	27/02/2006	11:30	Daylight	Raining	Straight	Towaway	Veered left off road into object	No

	24/01/2007	11:35	Daylight	Overcast/wet	Curve	Fatality	Veered right off road into trees	Speed
	09/03/2007	17:30	Daylight	Fine/Dry	Curve	Towaway	Veered right off road into trees	Fatigue
	10/04/2008	07:00	Daylight	Fine/Dry	Straight	Injury	Veered right off road into trees	Fatigue
	29/05/2008	16:30	Daylight	Fine/Dry	Straight	Towaway	Veered right off road into trees	Fatigue
	01/06/2009	10:30	Daylight	Fine/Dry	Curve	Towaway	Hit vehicle changing into left lane	No
	03/11/2010	20:00	Darkness	Fine/Dry	Straight	Towaway	Veered right off road into trees	No
	21/08/2011	08:58	Daylight	Fine/Wet	Curve	Injury	Veered right off road into trees	Speed
	22/10/2011	13:00	Daylight	Fine/Dry	Straight	Injury	Veered right off road into object	Speed and Fatigue
	22/01/2012	03:00	Darkness	Raining	Curve	Towaway	Veered right off road into trees	Speed
Southbound Entry	25/05/1996	10:00	Daylight	Fine/Dry	Straight	Injury	Hit object on road	No
	04/09/1996	05:10	Darkness	Fine/Dry	Straight	Injury	Vehicle hit pulling out into lane	No
	16/05/1998	20:55	Darkness	Raining	Straight	Injury	Veered left off road into utility pole	No
	01/10/2004	12:45	Daylight	Raining	Straight	Towaway	Veered right off road into trees	No
	23/04/2008	08:45	Daylight	Raining	Straight	Injury	Veered right off road into trees	Fatigue
	12/02/2009	12:20	Daylight	Overcast/wet	Straight	Towaway	Veered left off road into trees	No
	19/04/2009	19:00	Darkness	Raining	Straight	Towaway	Veered right off road into trees	No
	18/09/2009	13:46	Daylight	Fine/Dry	Straight	Towaway	Hit vehicle changing into right lane	No
	17/10/2009	06:50	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	27/04/2010	12:23	Daylight	Fine/dry	Straight	Towaway	Hit vehicle changing into right lane	Speed
	06/05/2011	18:00	Dusk	Fine/Dry	Straight	Injury	Rear end collision	No
	08/08/2013	08:40	Daylight	Fine/Dry	Straight	Towaway	Hit object on road	No
	08/08/2013	08:40	Daylight	Fine/Dry	Straight	Towaway	Hit object on road	No
	08/08/2013	08:40	Daylight	Fine/Dry	Straight	Towaway	Hit object on road	No

Service Centre Interchange								
	Date	**Time**	**Natural Light**	**Weather Conditions**	**Road Alignment**	**Degree of Crash**	**Type of Crash**	**Contributing Factors**
Northbound Exit	15/01/2000	09:10	Daylight	Raining	Straight	Towaway	Rear end collision	No
	09/12/2000	10:30	Daylight	Overcast/dry	Straight	Towaway	Hit vehicle changing into right lane	No
	10/08/2002	21:50	Darkness	Fine/Dry	Straight	Injury	Veered left off road into traffic island	Fatigue
	22/03/2005	19:30	Darkness	Raining	Straight	Injury	Veered right off road into traffic island	No
	21/03/2006	07:00	Daylight	Raining	Curve	Towaway	Veered right off road into trees	Speed
	15/08/2009	10:30	Daylight	Fine/Dry	Straight	Injury	Rear end collision	No
Northbound Entry	13/08/1997	17:30	Darkness	Fine/Dry	Straight	Towaway	Rear end collision	No
	02/11/1997	17:10	Daylight	Fine/Dry	Curve	Injury	Lane sideswipe	No
	22/06/1998	12:15	Daylight	Raining	Straight	Towaway	Hit vehicle changing into right lane	No
	07/11/1999	19:44	Daylight	Fine/Dry	Straight	Injury	Veered left off road into object	Speed
	01/07/2001	02:00	Darkness	Fine/Dry	Straight	Towaway	Veered right off road	Fatigue
	21/12/2002	07:00	Daylight	Fine/Dry	Curve	Towaway	Veered left off road into object	No
	28/11/2003	06:45	Daylight	Fine/Dry	Straight	Injury	Rear end collision	No
	30/06/2005	10:30	Daylight	Raining	Straight	Injury	Veered right off road into object	Fatigue
	22/01/2006	15:50	Daylight	Fine/Dry	Straight	Towaway	Veered left off road into object	No
	08/09/2007	00:30	Darkness	Raining	Curve	Towaway	Veered right off road	Speed
	01/12/2007	17:30	Daylight	Raining	Straight	Injury	Veered right off road	No
	07/09/2008	11:45	Daylight	Fine/Dry	Curve	Injury	Veered right off road into object	No
	19/11/2008	14:00	Daylight	Fine/Dry	Curve	Injury	Lane sideswipe	No
	15/02/2009	13:10	Daylight	Raining	Curve	Towaway	Veered left off road into object	Speed
	16/02/2012	09:00	Daylight	Fine/Dry	Curve	Towaway	Hit object on road	No
	03/08/2012	17:00	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	20/03/2013	12:30	Daylight	Fine/Dry	Straight	Towaway	Lane sideswipe	No
Southbound Exit	13/11/1996	04:55	Darkness	Fine/Dry	Straight	Injury	Hit parked vehicle	No
	02/06/2000	13:45	Daylight	Raining	Straight	Injury	Veered right off road into object	No
	23/09/2005	10:45	Daylight	Fine/Dry	Straight	Towaway	Hit vehicle changing into right lane	No
	03/12/2005	07:40	Daylight	Fine/Dry	Straight	Injury	Hit vehicle changing into right lane	No
	14/05/2006	12:00	Daylight	Fine/Dry	Curve	Injury	Veered right off road into traffic island	Speed

	05/05/2007	22:55	Darkness	Fine/wet	Straight	Towaway	Rear end collision	Fatigue
	17/07/2007	14:50	Daylight	Fine/Dry	Straight	Towaway	Veered right off road into trees	No
	10/06/2009	11:30	Daylight	Fine/Dry	Straight	Fatal	Veered left off road into parked vehicle	Fatigue
	09/09/2009	16:45	Daylight	Fine/Dry	Curve	Injury	Lane sideswipe	Speed
	04/03/2010	13:59	Daylight	Fine/Dry	Straight	Injury	Veered right off road	Speed
	04/02/2012	06:30	Daylight	Fine/Dry	Straight	Towaway	Veered left off road into object	No
	22/01/2014	09:30	Daylight	Overcast/dry	Straight	Towaway	Veered left off road into guardrail	No
	10/04/2014	21:18	Darkness	Raining	Curve	Towaway	Veered left off road into guardrail	Speed
	07/05/2014	09:45	Daylight	Fine/Dry	Curve	Towaway	Veered left off road into signpost	Speed
	08/11/2012	19:10	Darkness	Raining	Straight	Towaway	Lane sideswipe	No
Southbound Entry	04/04/1996	13:00	Daylight	Fine/Dry	Straight	Injury	Hit vehicle performing U-turn	No
	08/02/1997	19:25	Daylight	Fine/Dry	Straight	Injury	Veered right off road into bridge	No
	27/07/1997	09:15	Daylight	Raining	Straight	Towaway	Lane sideswipe	No
	07/10/1998	07:20	Daylight	Fine/Dry	Straight	Injury	Rear end collision	No
	18/11/2001	12:45	Daylight	Overcast/dry	Curve	Towaway	Veered right off road into object	Speed
	28/03/2002	07:00	Daylight	Raining	Curve	Towaway	Veered left off road into trees	Speed
	10/12/2006	12:00	Daylight	Fine/Dry	Straight	Towaway	Hit broken down vehicle	No
	01/10/2007	13:40	Daylight	Fine/Dry	Curve	Injury	Veered right off road into trees	No
	13/02/2008	12:00	Daylight	Raining	Curve	Injury	Veered right off road into traffic island	Speed
	27/10/2011	15:30	Daylight	Overcast/dry	Curve	Towaway	Veered left off road into object	Fatigue

Tuggerah Interchange								
	Date	**Time**	**Natural Light**	**Weather Conditions**	**Road Alignment**	**Degree of Crash**	**Type of Crash**	**Contributing Factors**
Northbound Exit	29/03/1998	09:30	Daylight	Overcast/dry	Straight	Injury	Veered left off road into traffic island	Speed
	04/10/1998	16:40	Daylight	Fine/Dry	Curve	Injury	Veered left off road into object	No
	02/12/1998	17:30	Daylight	Fine/Dry	Straight	Towaway	Hit parked vehicle	No
	19/01/1999	06:00	Daylight	Fine/Dry	Straight	Injury	Hit animal in lane	No
	22/11/1999	18:30	Daylight	Overcast/dry	Straight	Injury	Hit object on road	No
	22/08/2000	20:03	Darkness	Fine/Dry	Straight	Towaway	Rear end collision	No
	10/01/2001	14:00	Daylight	Fine/Dry	Straight	Injury	Lane sideswipe	No
	15/01/2001	09:30	Daylight	Fine/Dry	Straight	Injury	Rear end collision	No
	28/02/2002	13:45	Daylight	Raining	Straight	Injury	Head on collision, vehicle on wrong side	No
	05/03/2002	15:45	Daylight	Raining	Curve	Injury	Veered right off road into object	Speed
	25/08/2002	01:00	Darkness	Raining	Curve	Injury	Veered left off road into object	Speed
	01/09/2002	14:20	Daylight	Raining	Straight	Towaway	Veered left off road into object	No
	21/11/2002	01:00	Darkness	Raining	Curve	Towaway	Veered left off road into signpost	No
	17/04/2003	08:10	Daylight	Raining	Straight	Towaway	Veered left off road into trees	No
	12/09/2003	12:00	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	29/09/2003	11:05	Daylight	Fine/Dry	Straight	Towaway	Veered left off road into object	No
	04/10/2003	18:30	Darkness	Overcast/dry	Straight	Injury	Rear end collision	No
	23/03/2004	21:40	Darkness	Fine/Dry	Straight	Injury	Rear end collision	Alcohol and Speed
	01/10/2004	12:20	Daylight	Raining	Straight	Towaway	Lane sideswipe	No
	24/01/2005	14:45	Daylight	Overcast/dry	Straight	Towaway	Veered left off road into object	No
	25/04/2005	00:01	Darkness	Fine/Dry	Straight	Towaway	Veered right off road into object	No
	14/05/2005	15:00	Daylight	Overcast/dry	Straight	Towaway	Veered right off road into signpost	Fatigue
	22/12/2005	20:58	Darkness	Fine/Dry	Straight	Injury	Veered left off road into object	No
	17/05/2006	17:42	Darkness	Fine/Dry	Straight	Towaway	Rear end collision	No
	25/12/2006	06:46	Daylight	Overcast/wet	Straight	Towaway	Rear end collision	No
	29/12/2006	11:45	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	22/10/2007	16:00	Daylight	Fine/Dry	Straight	Towaway	Head on collision, vehicle on wrong side	No

	24/04/2008	18:00	Darkness	Raining	Straight	Towaway	Rear end collision	No
	17/05/2008	01:50	Darkness	Fine/Dry	Straight	Towaway	Veered right off road into object	Fatigue
	24/07/2008	11:30	Daylight	Raining	Curve	Injury	Rear end collision	No
	19/11/2008	19:35	Darkness	Fine/Dry	Straight	Injury	Rear end collision	No
	02/12/2008	16:00	Daylight	Fine/Dry	Straight	Injury	Hit vehicle changing into right lane	No
	07/12/2008	16:15	Daylight	Fine/wet	Straight	Towaway	Rear end collision	No
	16/12/2009	21:55	Darkness	Fine/Dry	Straight	Towaway	Veered left off road into object	No
	23/06/2010	04:55	Darkness	Raining	Straight	Towaway	Hit animal in lane	No
	05/10/2010	07:05	Daylight	Raining	Straight	Injury	Veered right off road into object	No
	12/12/2012	13:30	Daylight	Fine/Dry	Straight	Towaway	Hit vehicle changing into left lane	No
	01/03/2013	16:33	Daylight	Raining	Straight	Towaway	Veered left off road into parked vehicle	No
	23/02/2014	06:00	Dawn	Fine/Dry	Straight	Injury	Rear end collision	No
Northbound Entry	28/02/1996	13:25	Daylight	Fine/Dry	Straight	Towaway	Veered left off road into trees	Speed
	06/10/1997	18:45	Darkness	Raining	Straight	Towaway	Rear end collision	No
	11/10/1997	01:00	Darkness	Fine/Dry	Straight	Towaway	Veered right off road into traffic island	No
	14/11/1998	09:45	Daylight	Fine/Dry	Straight	Injury	Veered right off road into object	No
	12/12/1998	11:50	Daylight	Fine/Dry	Curve	Fatal	Hit parked vehicle, multi car pile up	No
	28/01/1999	12:10	Daylight	Raining	Straight	Towaway	Veered left off road into object	No
	01/03/1999	13:30	Daylight	Overcast/dry	Straight	Towaway	Veered right off road into object	No
	15/01/2000	09:00	Daylight	Raining	Straight	Injury	Rear end collision	No
	08/03/2000	15:45	Daylight	Raining	Straight	Injury	Rear end collision	No
	08/03/2000	15:45	Daylight	Raining	Straight	Towaway	Veered left off road into utility pole	No
	02/06/2000	10:30	Daylight	Fine/Dry	Straight	Towaway	Veered left off road	No
	01/07/2000	12:30	Daylight	Overcast/dry	Straight	Towaway	Veered right off road	No
	14/02/2001	17:10	Dusk	Raining	Straight	Towaway	Veered right off road into object	No
	29/11/2001	17:30	Daylight	Fine/Dry	Straight	Towaway	Veered left off road	No
	04/02/2002	09:50	Daylight	Raining	Straight	Injury	Veered left off road into trees	No
	25/12/2002	16:40	Daylight	Overcast/dry	Straight	Towaway	Lane sideswipe	No
	08/01/2003	12:15	Daylight	Fine/Dry	Straight	Towaway	Lane sideswipe	No
	19/01/2003	16:15	Daylight	Fine/Dry	Straight	Towaway	Hit vehicle changing into right lane	No
	15/04/2003	16:00	Daylight	Fine/Dry	Straight	Injury	Veered right off road	No
	17/04/2003	07:10	Daylight	Raining	Straight	Injury	Veered right off road into trees	No

	17/04/2003	08:05	Daylight	Raining	Straight	Towaway	Rear end collision	No
	17/04/2003	08:15	Daylight	Raining	Straight	Towaway	Rear end collision	No
	18/04/2003	10:30	Daylight	Raining	Straight	Towaway	Rear end collision	No
	27/04/2003	18:20	Darkness	Raining	Straight	Towaway	Hit broken down vehicle	No
	27/04/2003	18:20	Darkness	Raining	Straight	Towaway	Hit broken down vehicle	No
	13/05/2003	07:15	Daylight	Raining	Straight	Towaway	Veered right off road into embankment	No
	03/02/2004	13:00	Daylight	Fine/Dry	Straight	Towaway	Veered right off road into trees	No
	11/02/2004	17:50	Daylight	Raining	Straight	Towaway	Veered right off road into trees	No
	01/10/2004	14:07	Daylight	Raining	Straight	Towaway	Veered right off road into traffic island	No
	28/07/2005	11:00	Daylight	Fine/Dry	Straight	Fatal	Veered left off road into object	No
	17/12/2005	10:05	Daylight	Raining	Straight	Injury	Veered right off road into trees	No
	13/04/2006	19:00	Darkness	Raining	Straight	Injury	Rear end collision	No
	08/09/2006	13:55	Daylight	Overcast/dry	Straight	Towaway	Rear end collision	No
	15/11/2006	10:05	Daylight	Fine/Dry	Straight	Towaway	On road, out of control	No
	24/12/2006	16:17	Daylight	Raining	Straight	Injury	Rear end collision	No
	24/12/2006	16:30	Daylight	Raining	Straight	Towaway	Rear end collision	No
	22/03/2007	12:45	Daylight	Fine/Dry	Straight	Towaway	Veered right off road into trees	No
	01/12/2007	19:20	Darkness	Raining	Straight	Towaway	Veered left off road into trees	No
	03/12/2007	14:50	Daylight	Raining	Straight	Towaway	Veered right off road into object	No
	21/04/2008	10:10	Daylight	Raining	Straight	Towaway	Veered right off road	No
	01/09/2008	15:10	Daylight	Fine/Dry	Straight	Towaway	Veered left off road into object	No
	04/12/2008	16:10	Dusk	Fine/Dry	Straight	Towaway	Object hit vehicle	No
	17/01/2010	14:15	Daylight	Raining	Straight	Towaway	Veered right off road into object	No
	05/02/2010	14:25	Daylight	Raining	Straight	Towaway	Lane sideswipe	No
	27/08/2010	19:10	Darkness	Fine/Dry	Straight	Towaway	Hit object on road	No
	28/04/2011	09:21	Daylight	Raining	Straight	Towaway	Veered right off road into object	Fatigue
	24/05/2011	16:15	Daylight	Fine/Dry	Straight	Towaway	Veered right off road into object	No
	12/06/2011	15:15	Daylight	Raining	Straight	Towaway	Veered right off road into trees	No
	17/02/2012	14:55	Daylight	Fine/Dry	Straight	Towaway	Hit vehicle changing into left lane	No
	06/04/2012	09:00	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	27/12/2012	16:30	Daylight	Fine/Dry	Straight	Towaway	Hit vehicle changing into right lane	Speed
	14/01/2013	06:15	Daylight	Overcast/wet	Straight	Towaway	Hit road work equipment	No

	28/03/2013	20:10	Darkness	Fine/Dry	Straight	Towaway	Hit vehicle changing into right lane	No
	22/04/2013	12:25	Daylight	Fine/Dry	Straight	Towaway	Hit vehicle changing into right lane	No
	12/05/2013	11:30	Daylight	Fine/Dry	Straight	Towaway	Veered right off road into object	No
	21/03/2014	15:30	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
Southbound Exit	28/01/1996	10:20	Daylight	Fine/Dry	Straight	Injury	Hit vehicle changing into left lane	No
	10/06/2004	17:32	Darkness	Overcast/wet	Straight	Towaway	Veered right off road into object	No
	27/02/2005	08:40	Daylight	Overcast/dry	Straight	Towaway	Veered left off road into object	No
	18/06/2005	20:40	Darkness	Fine/Dry	Straight	Towaway	Lane sideswipe	Alcohol and Fatigue
	08/11/2006	18:24	Daylight	Fine/Dry	Straight	Injury	Veered right off road into traffic island	No
	17/09/2007	11:40	Daylight	Fine/Dry	Straight	Injury	Veered left off road into object	No
	30/01/2008	11:28	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	14/02/2008	09:37	Daylight	Overcast/wet	Straight	Injury	Rear end collision	No
	27/04/2009	05:20	Dawn	Fine/Dry	Straight	Injury	Veered left off road into object	Fatigue
Southbound Entry	20/11/2001	13:30	Daylight	Raining	Straight	Towaway	Veered right off road into signpost	No
	25/08/2002	13:50	Daylight	Raining	Straight	Towaway	Rear end collision	No
	02/01/2004	22:24	Darkness	Fine/Dry	Straight	Injury	Lane sideswipe	No
	29/06/2004	07:30	Daylight	Fine/Dry	Straight	Towaway	Veered right off road	No
	29/03/2006	11:20	Daylight	Raining	Straight	Towaway	Veered right off road into object	No
	12/02/2010	18:49	Dusk	Raining	Straight	Towaway	Veered right off road into trees	Fatigue
	16/09/2011	13:18	Daylight	Fine/Dry	Curve	Towaway	Hit vehicle changing into right lane	No
	03/10/2011	11:00	Daylight	Fine/Dry	Straight	Injury	Lane sideswipe	No
	08/10/2013	15:57	Daylight	Fine/Dry	Straight	Towaway	Veered right off road into trees	No

Mt Colah Interchange								
	Date	**Time**	**Natural Light**	**Weather Conditions**	**Road Alignment**	**Degree of Crash**	**Type of Crash**	**Contributing Factors**
Northbound Exit	19/06/1996	17:00	Dusk	Fine/Dry	Straight	Towaway	Veered left off road into embankment	No
	22/11/1996	18:15	Dusk	Raining	Straight	Injury	Rear end collision	No
	22/08/1997	09:30	Daylight	Fine/Dry	Straight	Towaway	Veered left off road into embankment	No
	23/01/1998	14:15	Daylight	Fine/Dry	Straight	Towaway	Veered left off road into object	Fatigue
	09/04/1998	19:15	Darkness	Raining	Straight	Towaway	Rear end collision	No
	18/07/2000	17:55	Darkness	Overcast/dry	Straight	Injury	Rear end collision	No
	01/12/2000	20:45	Darkness	Raining	Straight	Towaway	Veered right off road into object	Fatigue
	16/12/2000	15:00	Daylight	Fine/Dry	Straight	Injury	Veered right off road into object	No
	17/04/2001	06:58	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	11/07/2001	12:15	Daylight	Overcast/wet	Straight	Towaway	Rear end collision	No
	01/02/2002	18:50	Daylight	Raining	Straight	Towaway	Rear end collision	No
	28/02/2002	15:10	Daylight	Overcast/wet	Straight	Injury	Hit vehicle changing into right lane	No
	10/02/2004	15:35	Daylight	Fine/Dry	Straight	Towaway	Hit object on road	No
	30/07/2004	17:50	Darkness	Fine/Dry	Straight	Towaway	Hit broken down vehicle	No
	20/08/2004	17:05	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	05/11/2004	15:30	Daylight	Fine/wet	Straight	Towaway	Rear end collision	No
	09/02/2005	17:15	Daylight	Fine/Dry	Straight	Towaway	Hit object on road	No
	19/04/2005	19:25	Darkness	Fine/Dry	Straight	Injury	Other	No
	23/06/2005	06:00	Dawn	Fine/Dry	Straight	Towaway	Hit vehicle changing into left lane	No
	01/10/2005	09:45	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	09/01/2006	11:40	Daylight	Raining	Straight	Towaway	Rear end collision	No
	18/08/2006	16:45	Dusk	Fine/Dry	Straight	Injury	Veered left off road into trees	No
	12/02/2007	15:25	Daylight	Raining	Straight	Injury	Veered left off road into embankment	No
	12/11/2007	14:45	Daylight	Fine/Dry	Straight	Towaway	Lane sideswipe	No
	17/04/2008	22:52	Darkness	Fine/Dry	Straight	Towaway	Rear end collision	No
	16/07/2009	20:20	Darkness	Raining	Straight	Injury	Hit vehicle changing into left lane	No
	21/09/2010	19:50	Darkness	Fine/Dry	Straight	Injury	Lane sideswipe	No
	10/08/2011	23:04	Darkness	Fine/Dry	Straight	Injury	Lane sideswipe	No
	06/12/2012	12:15	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	Speed

	04/01/2014	09:45	Daylight	Fine/Dry	Straight	Injury	Rear end collision	No
	03/03/2014	20:15	Darkness	Raining	Straight	Injury	Rear end collision	No
Southbound Entry	24/01/1996	09:00	Daylight	Overcast/wet	Straight	Injury	Hit parked car	No
	09/11/1996	24:00	Darkness	Fine/Dry	Straight	Towaway	Rear end collision	No
	20/01/1998	08:30	Daylight	Fine/Dry	Straight	Injury	Out of control, on road	No
	30/09/1999	14:30	Daylight	Fine/Dry	Straight	Towaway	Veered left off road into trees	Fatigue
	01/12/1999	12:15	Daylight	Fine/Dry	Straight	Towaway	Veered left off road into trees	Fatigue
	07/08/2000	16:15	Daylight	Fine/Dry	Straight	Towaway	Veered right off road into trees	No
	10/10/2000	07:05	Daylight	Fine/Dry	Straight	Injury	Vehicle hit by object	No
	12/02/2001	08:15	Daylight	Overcast/dry	Straight	Towaway	Rear end collision	No
	28/08/2001	07:20	Daylight	Overcast/wet	Straight	Injury	Hit vehicle changing into left lane	No
	18/11/2001	13:00	Daylight	Overcast/wet	Straight	Injury	Veered left off road	Fatigue
	03/12/2001	13:20	Daylight	Overcast/dry	Straight	Injury	Veered left off road into embankment	Alcohol
	26/02/2002	19:00	Daylight	Fine/Dry	Straight	Injury	Lane sideswipe	Speed
	02/06/2002	17:55	Darkness	Raining	Straight	Injury	Rear end collision	No
	01/09/2002	21:00	Darkness	Overcast/wet	Straight	Towaway	Rear end collision	No
	15/04/2003	11:05	Daylight	Fine/Dry	Straight	Towaway	Hit object on road	No
	28/03/2005	15:50	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	22/07/2005	16:00	Daylight	Fine/Dry	Straight	Injury	Veered right off road into object	Fatigue
	10/04/2006	15:30	Daylight	Fine/Dry	Straight	Towaway	Hit vehicle changing into left lane	No
	14/04/2007	02:00	Darkness	Fine/Dry	Straight	Towaway	Rear end collision	No
	31/03/2008	07:50	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	15/07/2008	19:38	Darkness	Fine/Dry	Straight	Towaway	Rear end collision	No
	02/04/2009	07:45	Daylight	Overcast/wet	Straight	Towaway	Veered left off road	No
	01/05/2009	10:00	Daylight	Fine/Dry	Straight	Towaway	Veered left off road into embankment	No
	15/02/2010	07:45	Daylight	Overcast/wet	Straight	Injury	Rear end collision	No
	12/12/2010	01:25	Darkness	Fine/Dry	Straight	Towaway	Veered left off road into object	No
	03/12/2010	08:48	Daylight	Fine/Dry	Straight	Towaway	Rear end collision	No
	28/06/2012	10:28	Daylight	Overcast/dry	Straight	Towaway	Veered right off road into object	Fatigue
	17/07/2012	14:40	Daylight	Fine/Dry	Straight	Towaway	Hit vehicle changing into left lane	No
	19/05/2013	18:05	Darkness	Fine/Dry	Straight	Towaway	Hit vehicle changing into right lane	No
	30/04/2014	07:50	Daylight	Overcast/wet	Straight	Injury	Rear end collision	No

APPENDIX D – COST BENEFIT ANALYSIS

Values used in the cost benefit analysis are current values for this research and will not be current upon the completion of this research.

Time Frame = 25 years

Initial cost of installation = $45, 000 (3 lights per exit ramp)

Running cost per year per light = $3, 865

Total cost of Street lights over 25 years = 45000 + (3865 × 3 × 25)

= $334, 875

Number of accidents on lit exit ramps = 22 (run-off road type crashes)

Number of accidents on unlit exit ramps = 27 (run-off road type crashes)

Difference in number of accidents = 5

Using the study period of 18 years:

Therefore 5 ÷ 18 = 0.2777 reduction in run-off crashes per year for lit exit ramps

Now 0.2777 × 25 = 6.9444 reduction in run-off crashes per ramp over 25 years

Cost of run-off crashes = $153, 000 per crash

Crash costs saved over 25 years = $153, 000 × 6.9444

= $1, 062, 500 cost of crashes per ramp over 25 years

Cost Benefit ratio = cost of crashes ÷ cost of installation

= $1, 062, 500 ÷ 334, 875

= 3.17

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