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Faculty of Engineering and Surveying

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Research Project

A STUDY ON:

SAFETY AND EFFICIENCY BENEFITS OF IMPLEMENTING ZIP MERGE TREATMENTS IN NSW

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ABSTRACT

Merging has long been considered an issue for many road users. Motorists exercising their right of way and not allowing vehicles to merge across in a traditional 'give- way' merge has influenced road authorities to adapt. This has lead to the development of the zip merge system. A zip merge does not contain linemarking to separate vehicles throughout the merge and gives no priority to either vehicle. Instead, a 'one-for-one' approach is adopted, where motorist are encouraged to allow one vehicle in the adjacent lane to merge in front of them. In New South Wales, zip merging is allowed at all merge sites up to 80km/h. Currently most states around Australia are experiencing a transition period, which is seeing the phasing out of traditional merges, to be replaced by zip merges.

Design standards, including signposting, delineation and merge length available vary throughout Australia and around the world. Throughout this report, various standards are investigated in order to highlight potential safety and efficiency benefits of the zip merge system. Along with design standards, different road rules exist depending on the merge system adopted. Alternating rules on vehicle priority can result in distinct driver behaviour, ultimately impacting on safety and efficiency. Research shows when used correctly, the system provides benefits for both safety and efficiency.

Data collection involved investigation into how zip merges are currently performing. This was achieved through analysing video footage recorded at a number of zip merge sites in the Hunter Region of NSW. The observations looked at blinker and brake usage, the point where drivers were merging, along with general driver behaviours and interactions. It was found that blinker and brake usage is generally quite low (20% and 2% respectively). It was also found that drivers are utilising the available merge length (96% merged inside the taper) and displaying good driver behaviour (being courteous to other drivers). Utilising the length of merge available minimises merge angles between adjacent vehicles, which can potentially lower the severity of a crash. Utilising the entire merge also is an important factor, as it provides drivers more time perceive to and react to any situation requiring evasive manoeuvres.

Standards Australia currently suggest to use zip merges in speed zones of up to 80km/h. In NSW there has recently been a number of safety barriers installed near on-ramps on freeways, suggesting that give-way merges contain considerable deficiencies even on high

speed roads. The benefits of zip merges discussed throughout this report indicate that further investigation into freeway applications should be pursued. With an increasing investment into driver education and awareness programs, along with adopting the zip merging system on all road networks, it is likely that there would be a reduction in merge-related crashes.

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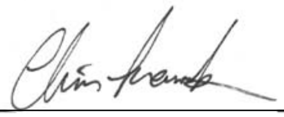

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C.J.Franks

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

Term	Definition
AADT	Average Annual Daily Traffic, the total yearly traffic volume in both directions at a road location, divided by the number of days in a year
Acceleration lane	A lane used to allow vehicles to increase speed without interfering with the main traffic stream. They are often used as part of an entry ramp to a freeway.
Alignment	The geometric form of the centreline of a carriageway in both horizontal and vertical directions.
Auxiliary lane	A portion of the carriageway adjoining the through traffic lanes, used for purposes supplementary to the through traffic movement.
Carriageway	The portion of a road or bridge used by vehicles, (inclusive of shoulders and auxiliary lanes).
Crossfall	The slope, at right-angles to the alignment, of the surface of any part of the carriageway, expressed as a percentage.
Freeway	A special form of controlled access road. Generally a divided road, with no access for traffic between interchanges and with grade separation at all intersections. Also known as an expressway.
Lane	A portion of the carriageway allotted for the use of a single line of vehicles.
Lane reductions	Where a lane is terminated forcing through vehicles to merge into an adjacent through lane

Level of Service	A qualitative measure of the traffic flow conditions and the drivers' perception of these conditions.
Merge	The point, the area or the manoeuvre where a line of traffic is required to join with another line when a lane is discontinued, by either a zip-merge or a lane change
Merge taper	A linear reduction in width to the lane. It is designed to allow vehicles enough distance to merge laterally into the adjacent lane.
Mutual sight distance	This is the sightline between traffic units approaching in each of the converging lanes in advance of a merge facility
Nearside	The left side of a vehicle moving foward (nearest the kerb)
Offside	The right side of a vehicle moving forward
Point of conflict	The road space desired by one vehicle or traffic movement, which is simultaneously required by another vehicle or traffic movement
RUM	An acronym for Road User Movement
Run-out area	This refers to the area of clear and traversable space at the end of the merge taper that can be used by vehicles that are not able to merge into the through lanes by that point.
Zip-merge	The merging of lines of traffic which does not require any linemarking to change lanes (i.e. by crossing a lane or continuity line)
85th percentile speed	The speed at or below which 85% of vehicles are observed to travel under free-flowing conditions past a nominated point

1. INTRODUCTION

1.1 Background

Merging on roads has continually received bad publicity, and considered a common problem amongst the road user community. Transport for NSW (2013b) states that merging is misunderstood by many road users, which lead to poor driving practices, unsafe manoeuvres, and can result in a reduction in road safety.

There are three basic elements contributing to road crashes; the road environment, driver behaviour and vehicle characteristics (Austroads 2009b). Driver behaviour together with the road environment makes up the majority of all road crashes (Austroads 2009b). It is therefore essential to provide a 'safe road environment' where road users can successfully negotiate road alignments and potential conflicts with other road users.

What is a conflict point?

A conflict point is the point at which a road user crossing, merging or diverging from a road or driveway conflicts with another road user using the same road or driveway (Simodynes, Welch & Kuntemeyer 2000). It is any point where the path of the two through or turning vehicles diverge, merge or cross. A visual explanation of conflict points are shown below in Figure 1.1. Also note that there is a fourth conflict point 'weaving', however it is classified as a combination of merging and diverging and so has not been included in this explanation.

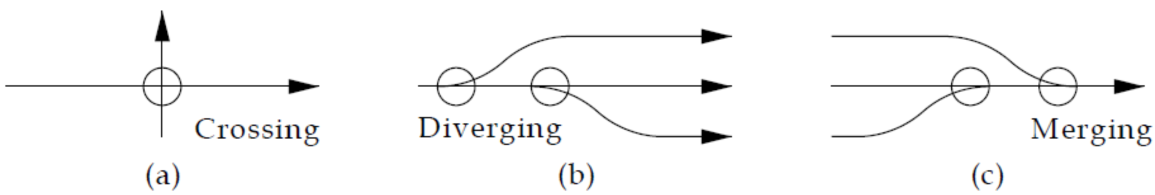


Figure 1.1– Road user conflicts: (a) Crossing, (b) Diverging and (c) Merging (Source: Simodynes, Welch and Kuntemeyer (2000))

Conflict points are commonly used to explain the accident potential of a roadway, where road users are forced to interact and perform manoeuvring. This study will focus on the merging conflict, as it is often regarded as a high-risk manoeuvre.

1.2 Zip merge

Zip (or Zipper) merges are being introduced throughout NSW and Australia. They are recommended by Australian standards to replace traditional merges in all locations within speed zones of 80km/h or less. The reason being is that zip merges are thought to have safety and efficiency benefits compared to that of a standard merge type. A previous study has shown that this merge system can considerably reduce queue lengths and reduces speed differences between adjacent vehicles leading into a merge (Styles & Luk 2006). An easy way to explain the difference between these two merge types is with a simple diagram like that shown in Figure 1.2.

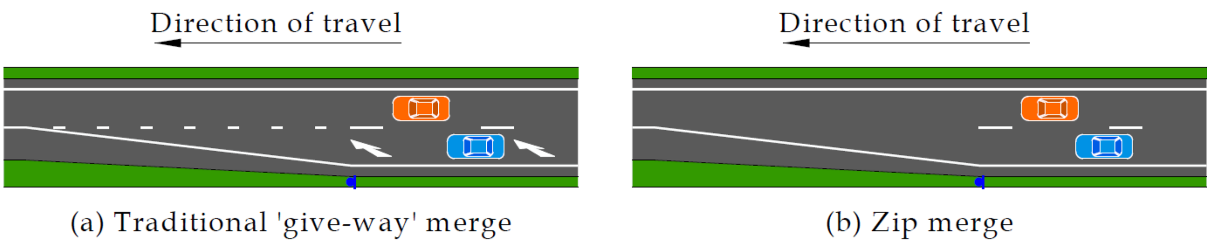


Figure 1.2 – Different merge treatments: (a) Traditional ‘give-way’ merge, (b) Zip merge

Looking at Figure 1.2, it can be seen that the most notable difference is that the standard merge (a) provides dotted (continuity) linemarking where the discontinuing lane starts to narrow. In the zip merge treatment (b) however, there is no linemarking present throughout the merge area. Straight away, some might think that having no lane delineation present would add to driver confusion and therefore have negative impacts on merging. Throughout this report, the search into factors that contribute to how the zip merge system operates is investigated. This will highlight key differences between the two systems, which show that when these contributing factors are combined, can impact how the merge system operates overall. Key differences include:

- Signposting & linemarking
- road rules and regulations
- driver behaviour and characteristics

These somewhat subtle differences along with inconsistent use of merge treatments and the lack of driver knowledge in NSW has been documented in this report, in an attempt to find what effect these factors have on safety and efficiency on our roads.

Merge locations and treatments vary widely worldwide. Often they also change markedly within jurisdictions. This leads to inconsistent road design and may potentially lead to a reduction in road safety due to misperception and confusion (Austroads 2010a). This report looks to show distinguishing features (such as signposting and linemarking) present at merge locations as well as highlighting the inconsistent use of these features that are present along NSW roads.

The United States and Germany have introduced dynamic late merge systems for areas where construction zones are forced to make lane closures on highways. In the United States, the 'zipper' merge system encourages motorists to stay in their lanes right up until the point where the discontinuing lane begins to narrow. The zipper system (Figure 1.3) also employs a one-for-one arrangement, where each vehicle allows 1 vehicle from the adjacent lane to merge in front of it (shown as 'TAKE YOUR TURN' in . This temporary system follows a similar concept to that of permanent zipper merges used in Australia and around the world.

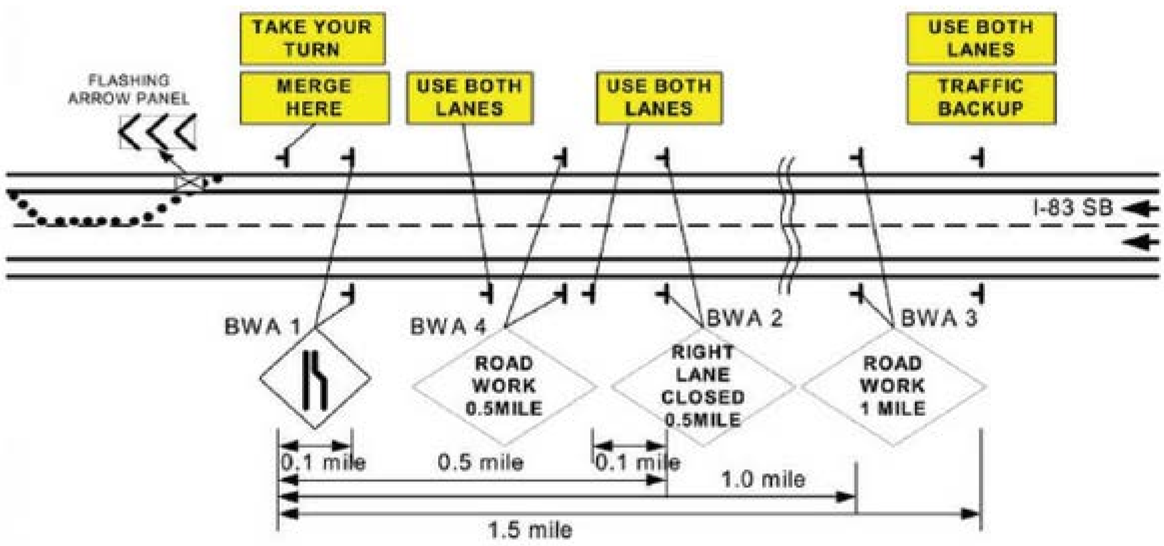


Figure 1.3 – Typical layout of a zipper system
(Source: http://www.workzonesafety.org/fhwa_wz_grant/atssa/atssa_dynamic_lane_merging)

Records of police-reported accidents generally form the basis for the statistical information, but are of little use in accident analysis due to their limitations, inaccuracies and incompleteness. For a site where multiple crashes have occurred, assumptions are usually made about the contributing factors and engineering solutions are often implemented in an attempt to minimise the risk of recurring crashes. However, it often takes several years before analysing the site in determining the success of the treatment adopted.

Part of the research undertaken in this report was to analyse video footage captured from multiple zip merge sites in the Newcastle region of NSW in an attempt to document key driver behaviours and characteristics demonstrated at these merge types. These behaviours and characteristics will hopefully provide a strong argument on the pros and cons of zip merge types, which will then be used to determine the suitability of where and when they should be adopted.

1.3 Project Aim

The project aim is to investigate zip merge treatments and evaluate their effectiveness in different merge environments (high/low speed). Highlight the inconsistency of merge treatments used in NSW. Determine the safety and efficiency aspects of this type of merge treatment and its appropriateness in different road environments.

1.4 Project objectives

The key objectives of the project are:

1. Research the background information (nationally and internationally) relating to the type of merge treatments and standards used under different road authorities.

2. Determine possible safety and efficiency benefits through analysing crash data and other relevant information.

3. Look at the possible data/scenarios to do ‘before and after study(s)’ to evaluate the effectiveness of zip merge treatments.

4. Analyse available data to help identify key parameters contributing to road crashes at merges.

2. LITERATURE REVIEW / BACKGROUND

2.1 Background

A literature review has been undertaken as part of this project which aims to provide information about previous research related to this topic. Documents have been sourced through libraries and over the internet, from both public and private sources to hopefully gain insight into the standards used and the underlying principles of how they have come about.

The safety of all road users is a key priority when it comes to road transport (Austroads 2010a). Different treatments implemented by the different road authorities can have varying levels of success when it comes to safety and efficiency (Styles & Luk 2006). This document seeks to determine contributing factors influencing these levels of varying success at zip merges and highlight where and when each should be used.

Driver behaviour can have a significant effect on the overall safety and efficiency of road networks, and driver knowledge, awareness and education is an important aspect of driver behaviour. This report also looks at studies and campaigns emphasising driver awareness and education.

2.2 Recognized geometric design guidelines

Geometric road design guidelines vary from country to country. In Australia, design guidelines and the implementation of road alignments and elements vary from state to state. This produces inconsistencies throughout interstate road networks, which could result in drivers unfamiliar to a particular section of road being confused. One of these situations is at the end of acceleration lanes and lane reductions, where the inevitable conflict of merging between drivers exists.

2.2.1 Austroads

Austroads is the association of Australian and New Zealand road transport and traffic authorities. The purpose of Austroads is to contribute to improved Australian and New Zealand transport outcomes. Austroads produce design guidelines and road safety documents that are designed to allow for harmonisation in the future. The Austroads organisation is made up eleven (11) members

- Roads and Maritime Services, New South Wales
- Roads Corporation, Victoria
- Department of Transport and Main Roads, Queensland
- Main Roads, Western Australia
- Department of Transport, Energy and Infrastructure, South Australia
- Department of Infrastructure, Energy and Resources, Tasmania
- Department of Planning and Infrastructure, Northern Territory
- Department of Territory and Municipal Services, Australian Capital Territory
- Department of Infrastructure, Transport, Regional Development and Local Government
- Australian Local Government Association
- New Zealand Transport Agency

Among the many publications Austroads provides are its 'Guide to Road Design' publications. Austroads, under its Technology Program, has established a Road Design Task Force. The Task Force consists of jurisdictional representatives from the 11 organisational bodies (mentioned above) and are responsible for considering all aspects of road design, including:

- Planning
- Design
- Construction
- Operation
- Maintenance
- Research and testing

Merge treatments are covered in Part 4A: Unsignalised and Signalised Intersections, of the Austroads Guide to Road Design publications (Austroads 2010b). Part 4A deals with auxiliary lanes, merge lengths and sight distance throughout merge areas. The following dot points is the list of standards this study intends to cover:

- Merge details – Acceleration lane/added through lane
- Merge taper lengths
- Sight distance required at merges

Austroads (2010a) states 'Auxiliary lanes are those lanes which are added adjacent to the through traffic lanes to enhance traffic flow and maintain the required level of service on the road.' Auxiliary lanes come in a number of different forms, the auxiliary lanes that are of concern in this report are:

- Overtaking lanes
- Acceleration lanes
- Lane drops

Overtaking lanes are provided to break up bunches of traffic and help improve traffic flow ease congestion (Austroads 2010b). The length of overtaking lanes can vary considerably depending factors such as traffic volumes, overtaking opportunities, topography, accident history as well as many other factors. If a lengthy overtaking lane (several kilometres) is provided, drivers can become unaware that the added lane is not continuous. This situation could then be considered as that of a lane drop, where two (or more) lanes of traffic have a lane reduced.

Figure 2.1 has been replicated, modified and simplified from Austroads (2010b, pp 70) and explains visually what lane drops (or reductions) and acceleration lanes are. Figure 2.1(a) shows a lane drop, where the number of lanes on the carriageway is reduced.

Austroads (2010b) states that acceleration lanes are provided at intersections and interchanges, they allow the vehicle entering the traffic stream to reach a speed equal to the 85th percentile speed of the through traffic. An example of an acceleration lane can be seen in Figure 2.1(b), where the vehicle from the minor road is expected to have reached 85th percentile speed before the start of the merge taper (Tm).

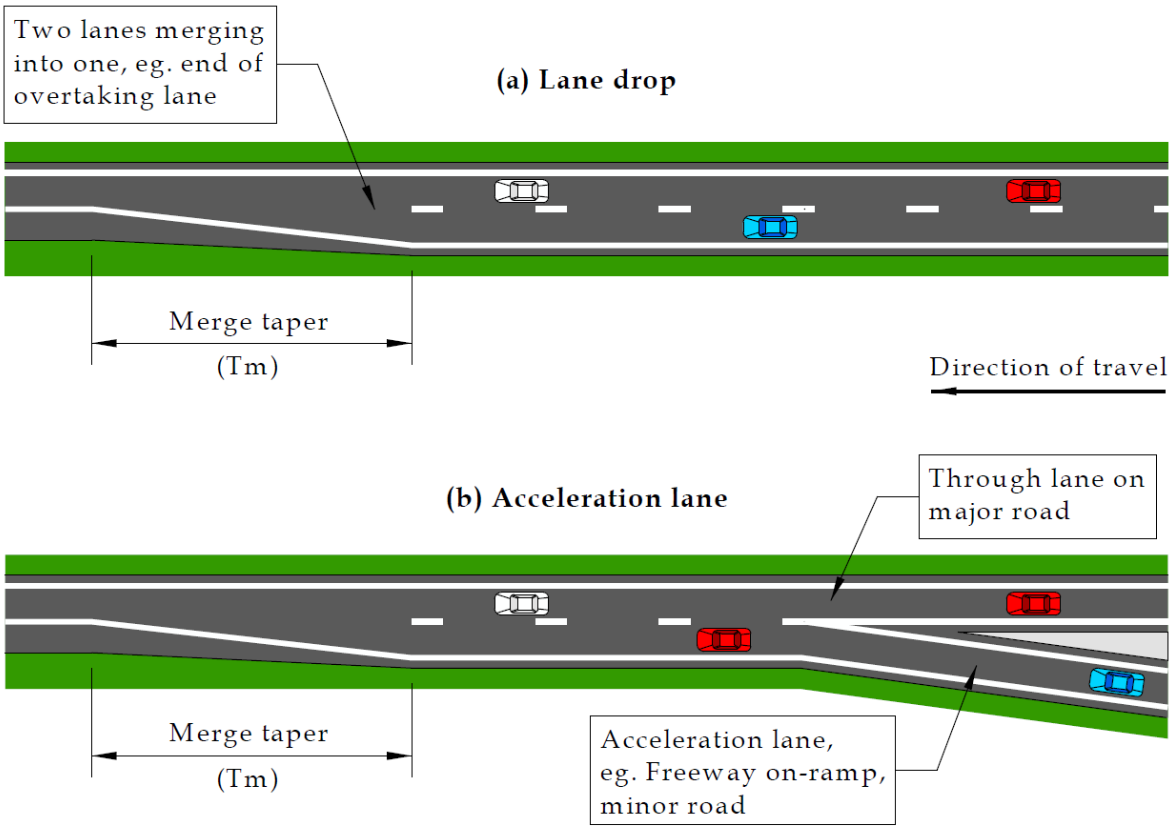


Figure 2.1 – Types of auxiliary lanes

Ideally, in acceleration lanes, merges should not take place at the beginning of the merge taper. Reasons for this are provided in Austroads (2010b) and summarised as:

- Merging vehicle is less likely to have built up appropriate speed
- The entry angle of the vehicle is likely to be less conductive to safety

These two reasons form a basis for the current research. Where the speed of adjacent vehicles will be looked at, as well as the angle at which vehicles tend to merge at zip merge sites. Vehicle speeds and merge angles are commented on in section 4 of this report.

Merge details

An acceleration lane has two basic design requirements:

- Acceleration length
- Merge length

Figure 2.2 shows a typical arrangement for an acceleration lane and the merge taper length (Tm).

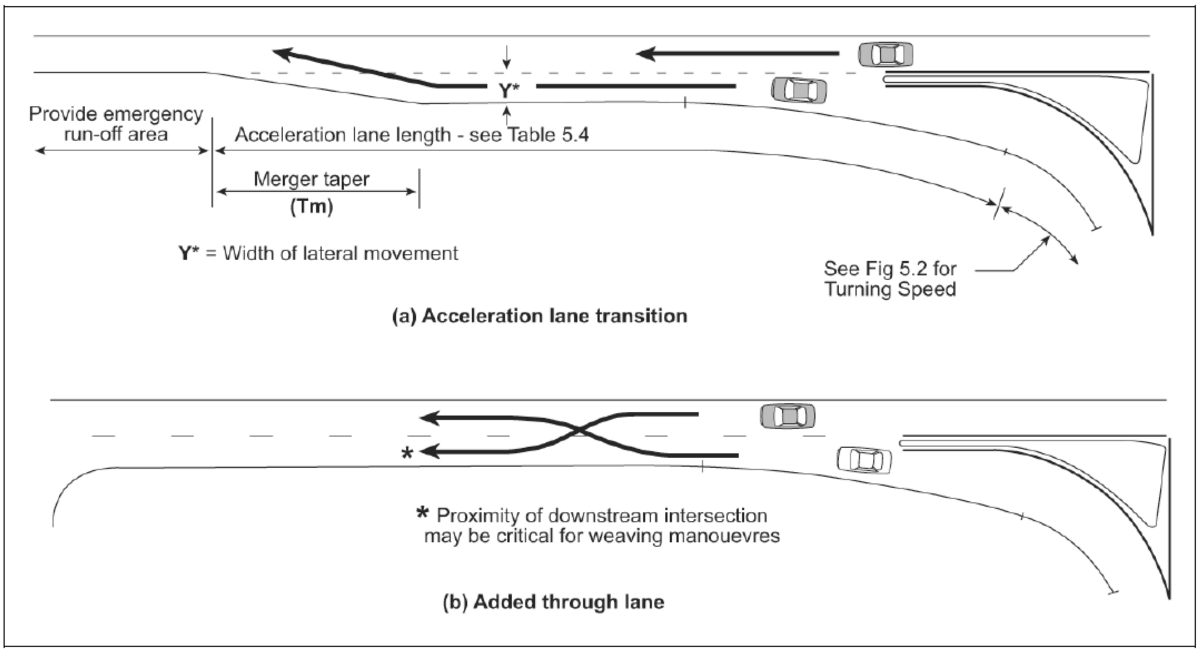


Figure 2.2 – Acceleration lane options (Austroads 2010b)

The merge taper (Tm) is the distance required for a vehicle to merge from the auxiliary lane into the adjacent through lane (Austroads 2010b). In this study, particular interest is on the length of the merge taper, which is an important aspect of merging as it will define how much time the merging vehicle will have to merge.

Merge taper lengths

The merge length for an acceleration lane or an auxiliary through lane can be calculated from the equation:

$$— \qquad (2.1)$$

Where

T_M = Merge taper length (m)

V = design speed (km/h)

S = rate of lateral movement

Acceleration lane merge – 1.0 m/s

Through lane merge – 0.6m/s

W = Amount of pavement widening (m)

Austroads (2010a) said for the termination of an auxiliary lane: 'Since this situation is equivalent to the dropping of a lane, drivers will be less prepared for the merging action than if they would be if merging from an acceleration lane'. Therefore, it is deemed necessary to adopt a lesser rate of 0.6 m/s for auxiliary lanes.

Austroads (2010b) states that for an acceleration lane: 'it is assumed that drivers are expecting that they will have to merge and can therefore comfortably merge at a lateral rate of 1.0 m/s'.

Site distance requirements at merges

The start and termination points of an auxiliary lane should be clearly visible to approaching drivers. The start point should be visible, prior to the point at which the warrant for the auxiliary lane is met to avoid potentially hazardous manoeuvres. The desirable visibility is given in Table 2-1

Table 2-1 – Sight distance to the start of an auxiliary lane (Austroads 2010a)

Design speed (km/h)	Distance for 4s of travel (m)	Rounded visibility distance (m)
50	56	60
60	67	70
70	78	80
80	89	90
90	100	100
100	111	115
110	122	125
120	133	135
130	144	150

Austroads (2010a) states that:

> *"The merge sight distance is measured from an eye height of 1.1m to an object of height of zero in the middle of the through lane, 20m past the start of the merge taper. As an absolute minimum, car stopping sight distance should be provided, measured from an eye height of 1.1m to an object height of zero at the start of the merge."*

2.2.2 New South Wales

The Department of Main Roads NSW (DMR NSW) was the states first documented road authority and was established in 1932. In 1989 DMR NSW combined with the Department of Motor Transport and the traffic authority to form the Roads and Traffic Authority (RTA). The RTA and NSW Maritime merged to became the Roads and Maritime Services (RMS) in 2012, which was part of the new strategy by Transport for NSW. However no updates to the RTA Road Design Guide have come as part of this new organisation. Therefore, the standards adopted in NSW will be taken from the Road Design Guide, along with any relevant RMS supplements.

In the year 2000, RTA published the Road Design Guide section 4; intersections at grade. Section 4.8.2.2 defined acceleration lanes, along with their use. Roads and Traffic Authority (2000) defined two options for acceleration lanes. The first type being a simple acceleration lane transition and the second, an addition of a through lane. Illustrations of these are represented in Figure 2.3 (a) and (b) respectively.

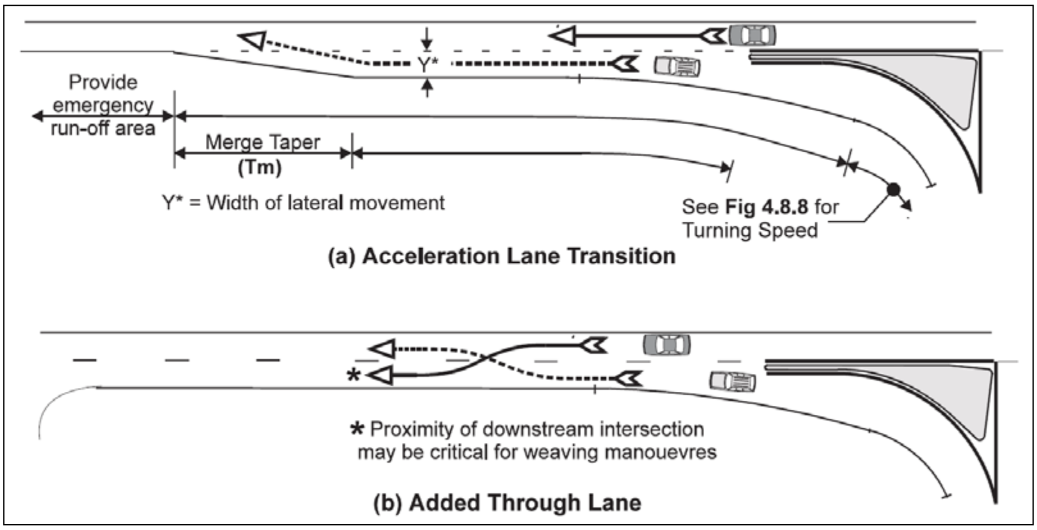


Figure 2.3 – Acceleration lane options (Roads and Traffic Authority 2000)

The acceleration lane transition (Figure 2.3 (a)) shows the merge taper (Tm) length which is the distance the merging vehicle has to merge safely into the through lane. This distance can be calculated using the following equation.

$$Tm = \frac{VY}{3.6S}$$

where

Tm = merge length (metres)

V = design speed (km/h)

S = rate of lateral movement
Acceleration Lane Merge - 1.0m/s
Through Lane Merge - 0.6 m/s

Y = width of lateral movement (metres)

Equation 2.2 – Merge Taper Length (Roads and Traffic Authority 2000)

The rate of lateral movement (S) in Equation 2.2Equation 2.2 – Merge Taper Length shows different values for acceleration lane and through lane merge treatments. Reasons for this are explained in Austroads (2010a), where it states that drivers would be less prepared in the situation of dropping a through lane compared to that of a driver merging from an acceleration lane.

2.2.3 Queensland

In 2002, the Department of Transport and Main Roads QLD (TMR) published 'Road Planning and Design Manual' Chapter 13: Intersections at Grade, along with Chapter 15: Auxiliary Lanes. These two documents provide guidance for the geometric design of auxiliary lanes and merge lengths used in Queensland.

A very similar diagram which is used in the RTA guidelines for acceleration lanes and added through lanes is adopted also in (TMR 2006).This is shown in Figure 2.4.

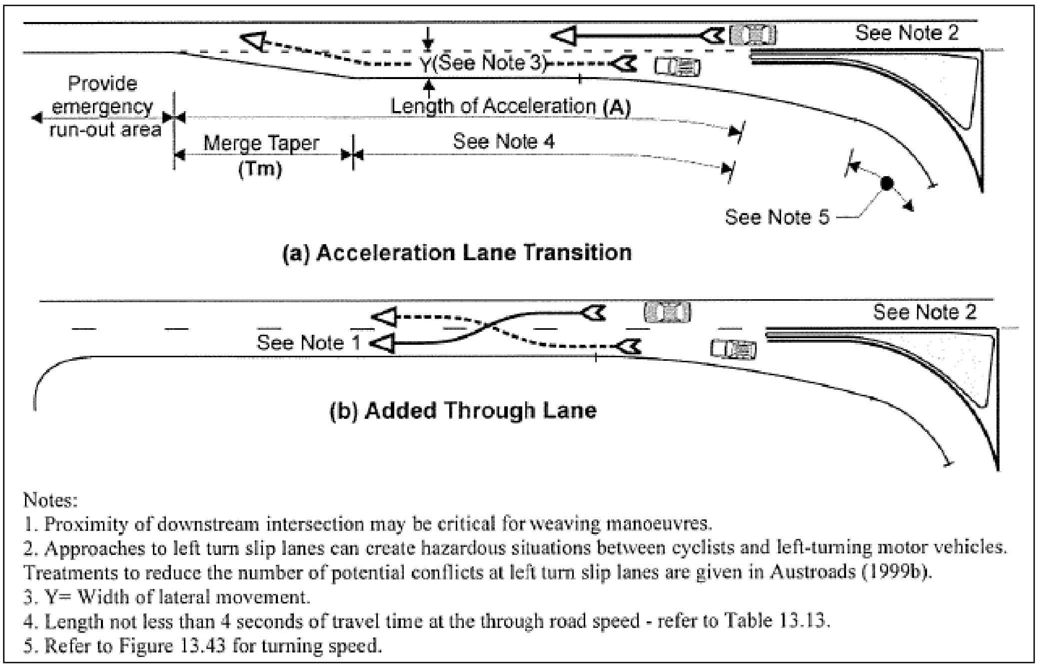


Figure 2.4 – Options for Auxiliary (TMR 2006)

Once again, the adopted formula for the merge taper is the same as the RTA, which is given in Equation 2.3

$$T_m = \frac{V \times Y}{3.6 \times S}$$

where:

T_m = merge length (m)

V = mean free speed (km/h)

Y = width of lateral movement (m)

S = rate of lateral movement

Acceleration Lane Merge - 1.0m/s

Through Lane Merge - 0.6 m/s

Equation 2.3 – Merge Taper Length (TMR 2006)

Equation 2.2 and 2.3 show that merge tapers adopted by the RTA and TMR respectively produce identical results for the desirable merge lengths. Figure 2.5 shows the merge geometry at a lane reduction site.

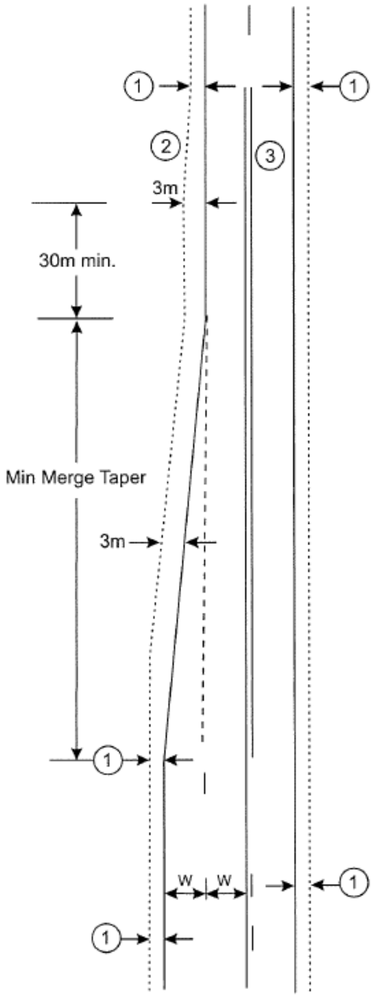


Figure 2.5 – Lane reduction showing merge geometry (TMR 2006)

Note the 30 metre (min) dimension that is proposed as the vehicle run-out area (Figure 2.5). TMR (2006) recommends Continuing pavement width (3m) in the shoulder from the beginning of the merge taper, till at least 30 meters after the finish of the taper is a desirable treatment noticing the

This extra width allows an errant vehicle that has not been able to merge correctly extra pavement area clear of any obstacles and hazards providing added safety benefits at many merge sites (TMR 2006). For that reason, the run-out area has been identified as one of the key criteria for site investigations (section 3).

2.2.4 Western Australia

Main Roads Western Australia (MRWA), formerly the Main Roads Department, is the State's roads agency responsible for managing and implementing the policies on the main roads. Supplements to the Austroads Guide to Road Design (GRD) Part 3 and 4 have been developed which takes precedence over Austroads Guide to Road Design series and Standards Australia (2009).

In section 9.9.2 of the Main Roads supplement to Austroads Guide to Road Design Part 3, MRWA (2014a) states 'the location of the termination point is the most critical component of auxiliary lane design. It is important that the termination is clearly visible to approaching traffic and provides sufficient sight distance to allow a smooth and safe merge between fast and slow vehicle streams'.

Austroads suggests the 0.6m/s merge rate only for when there is a lane reduction of a through lane (where vehicles are likely unaware of the merge ahead), otherwise the value 1.0m/s is recommended. However, MRWA (2014b) has adopted a merge rate of 0.6m/s at all merge treatments.

In section 9.9.2 of Main Roads supplement to Austroads Guide to Road Design Part 3, MRWA (2014a) states that a key component of deciding when to end an auxiliary lane is to provide safe stopping sight distance in both directions from the start of the merge. 'the distance is required to allow the opposing traffic to see the merging vehicles and to take appropriate actions if the merging vehicle strays onto the wrong side of the road. The detail of the merge taper mentioned in the supplement can be seen in Figure 2.6.

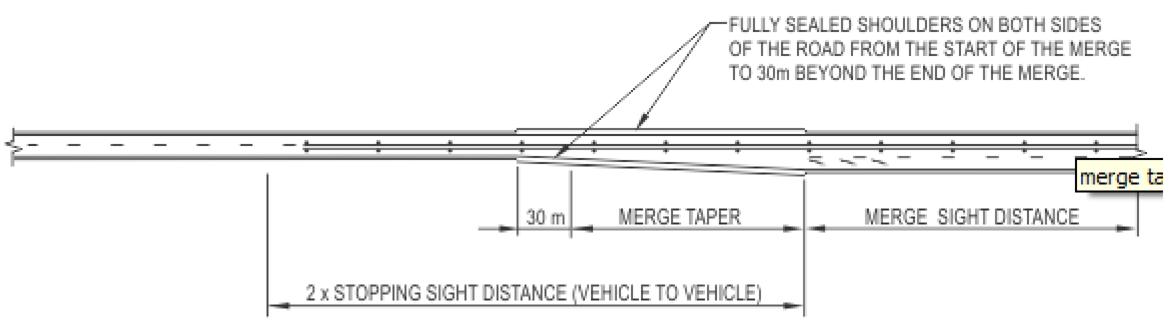


Figure 2.6 – Merge Taper Detail (MRWA 2014)

The merge taper shown in Figure 2.6 does not show a continuity line, which is a common practice on state roads in Western Australia.

MRWA is the only Australian jurisdiction that allows zip merging at freeway on-ramps. Styles and Luk (2006) stated that The Department for Planning and Infrastructure, Western Australia gives drivers the following directions:

> *"During merging you must give way to another vehicle if any part of the other vehicle is ahead of your vehicle."*

2.2.5 United States

Many of the standards used in Australia and around the world have come from studies and design guidelines produced in the US. A lot of the design guidelines and specifications that RMS use are based on studies undertaken by the American Association of State Highway and Transportation Officials (AASHTO) and the National Cooperative Highway Research Program (NCHRP). AASHTO in the US is the equivalent to that of Austroads in Australia, and just like Austroads have a 'Guide to Road Design' publication, AASHTO has produced a similar publication 'A Policy on Geometric Design of Highway and Streets'.

Although covering basic design criteria, AASHTO does not go into detail about the lengths required for merging, or formulas used. Therefore, the California Department of Transportation (Caltrans) has been sourced for the technical details for merge arrangements.

Merge details

Caltrans (2006b) mentions that entering traffic merges most efficiently with the through traffic when the merging angle is less than 15 (1:7) degrees and when speed differentials are at a minimum.

The U.S Department of Transportation's Federal Highway Administration has developed a Manual on Uniform Traffic Control Devices (MUTCD). This manual defines the standards to be used nationwide, thus providing simple and consistent delineation of road networks across the United States.

This study has looked at Parts 2 and 3 of the MUTCD, which deal with signs and markings respectively. The delineation standards at lane reductions were sourced from U.S. Department of Transportation (2009b) and can be seen in Figure 2.7.

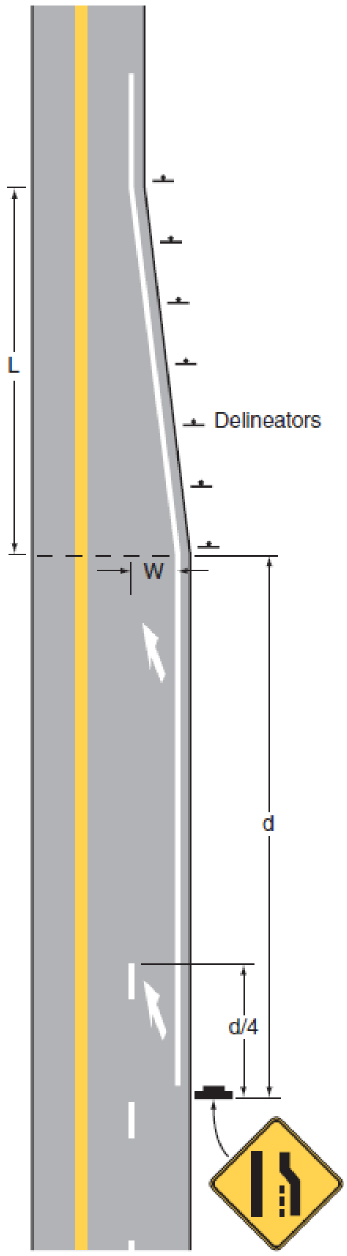


Figure 2.7 - Lane reduction markings (U.S. Department of Transportation 2009b)

The standard lane reduction (Figure 2.7), shows that the Department of Transportation in the U.S not only excludes linemarking throughout the merge taper, but excludes for a length of 3d/4, where d is the distance to an advanced warning sign.

The distance for advanced warning signs is found in Section 2C of the of the MUTCD. This table has been sourced from the U.S. Department of Transportation (2009a) and shown in Table 2-2.

Table 2-2 –Placement of advanced warning signs (U.S. Department of Transportation 2009a)

Posted or 85th-Percentile Speed	Advance Placement Distance[1]								
	Condition A: Speed reduction and lane changing in heavy traffic[2]	Condition B: Deceleration to the listed advisory speed (mph) for the condition							
		0[3]	10[4]	20[4]	30[4]	40[4]	50[4]	60[4]	70[4]
20 mph	225 ft	100 ft[6]	N/A[5]	—	—	—	—	—	—
25 mph	325 ft	100 ft[6]	N/A[5]	N/A[5]	—	—	—	—	—
30 mph	460 ft	100 ft[6]	N/A[5]	N/A[5]	—	—	—	—	—
35 mph	565 ft	100 ft[6]	N/A[5]	N/A[5]	N/A[5]	—	—	—	—
40 mph	670 ft	125 ft	100 ft[6]	100 ft[6]	N/A[5]	—	—	—	—
45 mph	775 ft	175 ft	125 ft	100 ft[6]	100 ft[6]	N/A[5]	—	—	—
50 mph	885 ft	250 ft	200 ft	175 ft	125 ft	100 ft[6]	—	—	—
55 mph	990 ft	325 ft	275 ft	225 ft	200 ft	125 ft	N/A[5]	—	—
60 mph	1,100 ft	400 ft	350 ft	325 ft	275 ft	200 ft	100 ft[6]	—	—
65 mph	1,200 ft	475 ft	450 ft	400 ft	350 ft	275 ft	200 ft	100 ft[6]	—
70 mph	1,250 ft	550 ft	525 ft	500 ft	450 ft	375 ft	275 ft	150 ft	—
75 mph	1,350 ft	650 ft	625 ft	600 ft	550 ft	475 ft	375 ft	250 ft	100 ft[6]

From Table 2-2, at 50 mph (80km /h) the distance for the placement of an advanced warning sign in a potential stop situation (condition B) is 250 ft, or approximately 76m. Now, looking at Figure 2.7, the linemarking finishes 3d/4 from the start of the merge taper. This would give a value of approximately 57m in an 80km/h speed environment.

Merge Taper lengths

The lane reduction markings (Figure 2.7) shows that no linemarking exists inside the merge taper, which is the same as zip merge treatments in Australia. The merge length (L) provided by Caltrans (2009) is given in the following formulas:

For speeds of 45 mph or greater:

$$L = WS$$ (2.4**Error! Bookmark not defined.**)

For speeds of 45 mph or less:

$$L = WS^2/60$$ (2.5)

Where:

L = length of taper in feet

S = Posted speed

W = Offset in feet

Sight distance requirements

AASHTO (2011) states that the driver should have full view of any point of separation, for both merging and diverging, far enough in advance of reaching that point to make the appropriate decision concerning desired direction.

AASHTO (2011) breaks the stopping sight distance (SSD) down into two components; the distance travelled the perception-reaction time (PRT), and the manoeuvre time (MT). Where:

- Perception-reaction time is the time it takes for a road user to realise that a reaction is needed due to a road condition. AASHTO (2011) allows 1.5 seconds for perception time, and 1.0 seconds for reaction time.
- For the breaking distance AASHTO (2011) uses a deceleration rate of 11.2 ft/s^2 (3.4 m/s^2), which it suggests that approximately 90% of all drivers decelerate at rates greater than that.

The stopping sight distance has been sourced from Caltrans (2006a) and is presented below in Table 2-3.

Table 2-3 – Values for Stopping Sight Distance in the U.S (Caltrans 2006a)

Design Speed (mph)	Stopping (ft)
10	50
15	100
20	125
25	150
30	200
35	250
40	300
45	360
50	430
55	500
60	580
65	660
70	750
75	840
80	930

2.3 Australian standards

Standards Australia seeks to provide consistency and uniformity of traffic control devices. Inside this document is a section that covers general treatments of sign posting at lane reductions (merges). It also recommends when each type of merge treatment should be used, and why. General treatments at lane merges are found in section 4.7.2 of AS1742.2 – 2009.

Standards Australia (2009) states that the zip-merge treatment is recommended in all cases where a lane is discontinued, except where:

- General lane change – continuity line should be used where the 85^{th} percentile speed is greater than 80km/h
- Expressway type entry ramp (shown in Figure 3.3 – AS1742.2 (need figure))

This says that zip merges are recommended for speed environments of 80km/h or less. Also, no facilities in NSW have employed the use of zip merging on freeways, therefore in the analyses section of this report, focus will be on non-freeway merge locations. An RMS supplement to the AS1742 (RMS 2013) states that:

> *"Zip Merges are used when the speed of the vehicles in each lane are similar. i.e. less than 20% difference in speed."*

2.3.1 Signposting

Roadways should be designed to reduce the need for driver decisions and reduce unexpected situations. AASHTO (2011) states that the number of crashes increases with the number of decisions that need to be made by the driver. Signage and marking is essential to the efficient and safe operation of roads (Austroads 2009a).

Signposting plays a major role in providing meaningful information allowing drivers to make informed decisions. Austroads (2009a) says it is essential that signposting provides clear and logical cues to drivers, therefore consistent signposting implementation is imperative to driver decision making, which in turn provides added safety to road transport.

Figure 2.8 shows a general layout of the two types of merge treatments used, along with the standard signposting used at each of the two merge types.

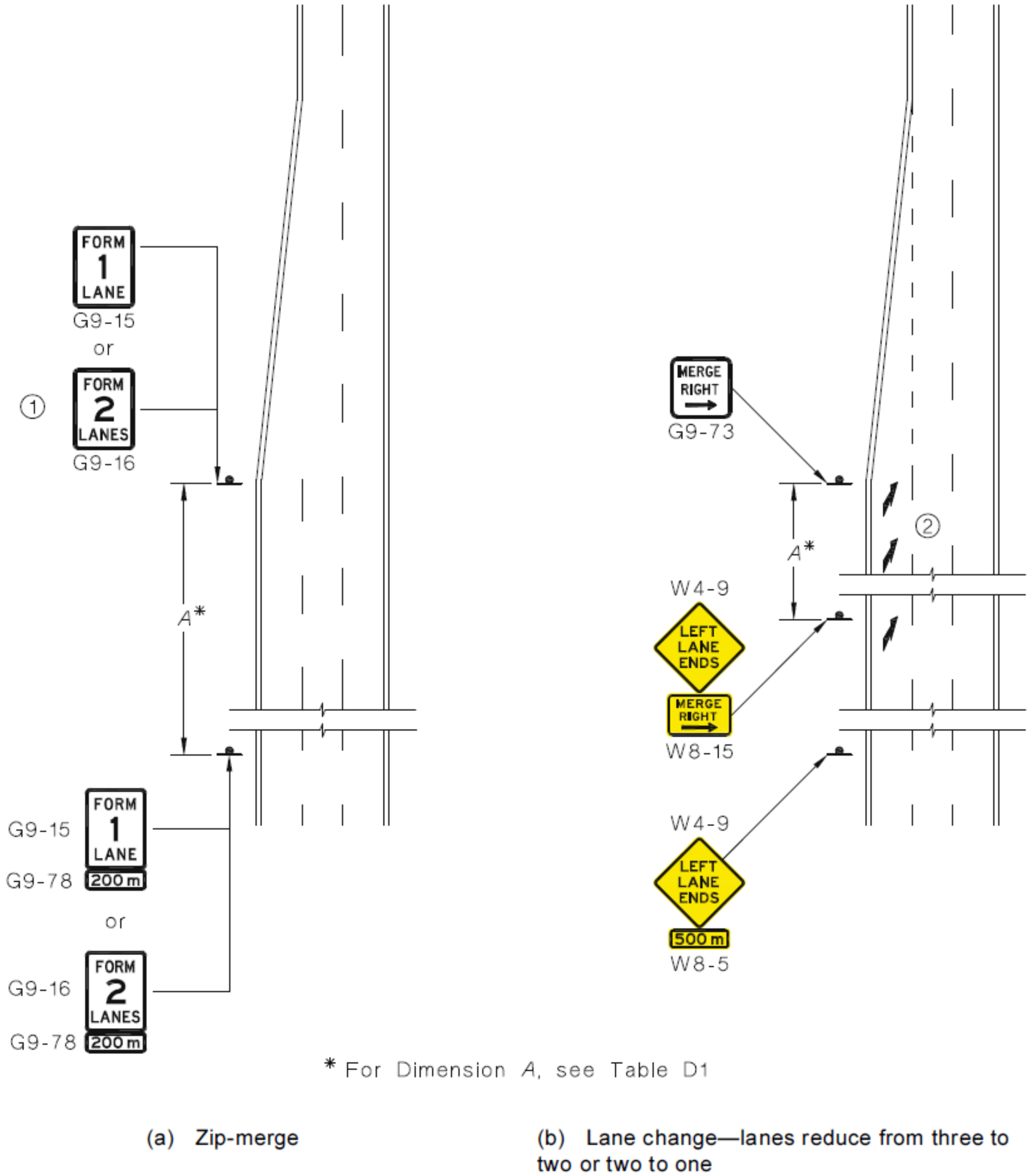


Figure 2.8 – Signposting treatments at lane reductions (Standards Australia 2009)

Looking at the signposting in Figure 2.8, it can be seen that the 'LEFT LANE ENDS, MERGE RIGHT' signs that are present in a traditional lane reduction situation have been replaced with 'FORM 1(2) LANES' signs. Further analysis into the signposting treatments at merge sites highlights a number of significant differences that could potentially have an effect on the operation of road systems.

Standards Australia (2014) uses a coding system starting with a letter prefix, as shown below to denote class of sign:

R-Regulatory signs

W-Warnings signs

G and GE- Direction signs and free-standing route markers

T-Temporary signs

D-Hazard markers

Taking a closer look into the signs used at merges, the present study finds a number of noticeable differences, although it is unclear how much (if any) effect these differences may have on the driver. The signposting used on approach (presented in Figure 2.8) to merge treatments are shown again in Figure 2.9.

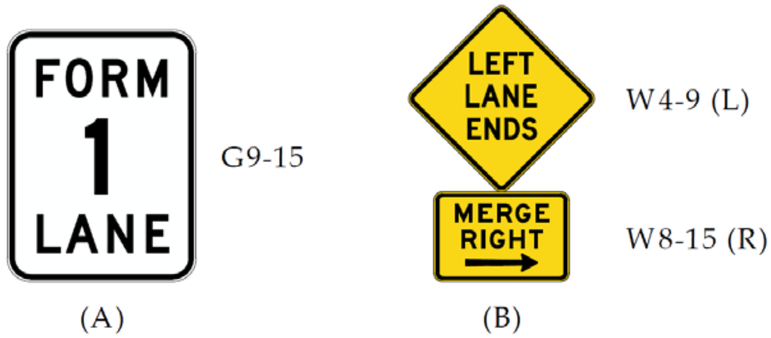


Figure 2.9 – signage used at merges - (A) zip, (B) give-way (Standards Australia 2009)

The first key difference is the coding system, with the zip merge sign (Figure 2.9(A)) starting with a 'G' which according to Standards Australia (2014) is a 'Directional' sign. However, looking at a give-way merge sign (Figure 2.9(B)), the first letter is a 'W' which according to Standards Australia (2014) is a 'Warning' sign.

Standards Australia (2014) describes the functional use of each of these signs and is summarised below:

- Warning signs (Type W) - To warn road users of unexpected or hazardous conditions on or adjacent to the road.
- Direction signs (Type G) - To inform and advise road users of directions, destinations, route names, and distances.

Also, Standards Australia (2014) states that the diamond shape is used solely for warning signs. The definition of a warning sign (Standards Australia 2014) indicates that the driver is being warned of an approaching hazard at locations where give-way merges occur adopting standard signposting.

Another key consideration of signposting is the sizing of signs. Standards Australia (2014) gives insight into different classes of signs and when they should be adopted:

- For most standard signs, a range of sizes designated A (smallest) up to B, C, or D is provided
- The A size should normally be used only where the 85th percentile approach speed is less than 70 km/h
- Progressively larger signs should be used as approach speeds become higher

Following on from the reasoning from sign sizes, this study will now compare the 'G9-15', the 'W4-9' and the 'W8-15' sign in both B and C sign classes. This is shown in Table 2-4.

Table 2-4 – Comparison of signpost sizes (Standards Australia 2009)

Sign Index	Size B Dimensions (mm)	Area (m^2)	Size C Dimensions (mm)	Area (m^2)
G9-15	900 x 1200	1.08	1200 x 1600	1.92
W4-9(L)	750 x 750	0.28	900 x 900	0.41
W8-15(R)	750 x 500	0.38	900 x 600	0.54

Table 2-4 shows that there is a significant difference between the size of signposting used are the different merge locations. The difference has been summarised as:

- The G9-15 sign is 75% and 78% larger than the W4-9 sign in class B and C respectively
- W4-9 and W8-15 together only account for 61% and 50% of the overall size of G9-15 sign in class B and C respectively
- G9-15 text is twice the size of W4-9 and W8-15 text, yet contains 40% less words

Signs are an essential part of the road traffic system, used to transfer information to the road user. A key consideration of signposting should be to minimise the time taken by the road user in locating, reading and processing signs. Standards Australia (2014) states that their message should be consistent, and their design and placement coordinated with the road geometric design.

Taking these considerations into account, the G9-15 could potential provide for safer road operation over the W4-9 and W8-15 signs, due to:

- A greater visual impact as the sign is considerably larger
- Less and Larger text, making it quicker and easier to read

In 2009 Parsons Brinkerhoff were commissioned by the NRMA to undertake a road safety audit of merge facilities in high speed environments in Sydney (Zhong & Chee 2009).

The audit looked at 124 merge sites, Zhong and Chee (2009) reported that 90 (73%) of the merge facilities investigated contained signage deficiencies either related:

- Incorrect signs
- Inconsistent use of signs
- Poor sign placement or
- Missing signs.

This highlights the fact that there is substantial signposting inconsistencies on roads In NSW. As signposting is an important part of providing important information to drivers, failure to deliver this information has the potential to reduce road safety.

2.4 Australian road rules

The Australian Road Rules are a comprehensive set of road rules to be followed by all road users. It is essential in providing Australian motorists with not only an understanding of the rules, but also the obligation each individual has when driving on Australian roads in providing safe and efficient journeys.

Road rules apply for the different type of merge situations, the rules that will be looked at in this document are road rules 148 and 149. National Transport Commission (2012) explains Australian road rule 148, which refers to a driver that is changing (or merging into) lanes across marked lines. In Figure 2.10, the red vehicle (B) is merging across a continuity line and must give way to the green vehicle (A) irrespective of which vehicle is in front.

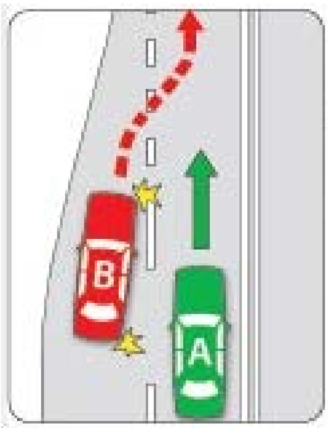


Figure 2.10 – Merging into a marked lane (National Transport Commission 2012)

This situation is common across merge situations in NSW, whether it be at the end of an acceleration lane where two roads meet, or an on-ramp onto a motorway. In many instances when drivers fail to merge (e.g. stop, or slow down in the acceleration lane) for whatever reason, other vehicles are forced to either slow down as well or make evasive manoeuvres. This situation will result in:

- Interruptions of the traffic flows
- traffic in-efficiencies and breakdowns of traffic flows
- large speed differentials between adjacent lanes
- increased risk of a crash
- safety concern for motorists

Australian road rule 149 is explained by National Transport Commission (2012), this rule applies to a drivers merging into an single unmarked lane (i.e. zip merge). Figure 2.11 shows an example of this, where the green vehicle (A) is crossing over an unmarked lane at a merge location, however, unlike road rule 148 the vehicle in front at the merge point has the right of way.

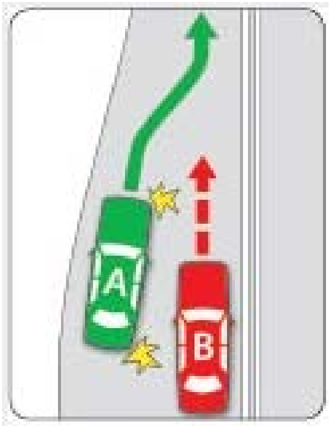


Figure 2.11 – Merging into an unmarked lane (National Transport Commission 2012)

In terms of safety and efficiency, the type of merge shown in Figure 2.11, theoretically makes sense as long as the situation includes:

- Vehicles travelling at a similar speed
- Both drivers being aware of the road rules in place, and
- Good driver behaviour is being adopted

The warrants for zip merges set by Standards Australia (2009), which include vehicles in adjacent lanes to be travelling at a similar speed. This warrant is mentioned in section 2.3 of this report.

2.5 Factors affecting safety and efficiency at merge locations

Zhong and Chee (2009) undertook a study of merge facilities in high speed environments in Sydney. In the study, they were able to identify factors that were most likely to affect the safety performance of merge facilities. these factors are listed below:

- Advanced warning of merging requirements: This includes providing warning of the upcoming merge, as well as providing warning that is an accurate reflection of the type of merge and road users requirements at the merge facility
- Mutual sight distance
- Guidance from line and pavement marking: This includes the provision of pavement arrows (where appropriate), the delineation of gore areas (where on ramps occur)
- Merge length available
- Run-out area
- Merge configuration and priority: This refers to the clarity of guidance and warning devices (i.e. signs and linemarking) regarding which vehicle has priority and right-of-way at the merge facility.

124 merge facilities were examined as part of the report by Zhong and Chee (2009). The report showed that a high number of safety deficiencies existed on the merge facilities investigated. These deficiencies are summarised below:

- 90 (73%) of facilities contain signage deficiencies
- 37 (30%) of the facilities provide poor mutual sight distance
- 27 (22%) provide a short merge length
- 55 (44%) of the facilities provide a poor run-out area

2.5.1 Capacity

Nemeth and Rouphail (1983) explain that drivers seek out gaps and that they will accept small gaps in a merge situation. Nemeth and Rouphail (1983) also point out that traffic flow in merges only becomes interrupted when traffic flow exceeds a threshold value (1250 vehicles per hour for a two lane merge situation), which results in there being insufficient gaps to allow the merge process to proceed. This figure of 1250 vehicles per hour (vph) is noted as a possible factor affecting results for the site observations discussed in section 3.3 of this report.

2.5.2 Merge angles

One of the factors affecting safety mentioned by.Austroads (2009a), is the angle of impact. Austroads (2009a) proposes that by eliminating high angles at conflict points (such as a merge), not only can it reduce the number of crashes, but ensure crashes are less severe. Merge angles is of significant interest, as it is easily identifiable during site observations.

2.5.3 Theories of safety and efficiency benefits

The Danish road directorate published their 'Merging Contra Give Way When Entering a Motorway' report in 1995 (Rysgaard & Nielsen 1995). According to the report, at the time, traffic regulations for almost all the European countries gave priority to motorway traffic. In Denmark however, motorway traffic had to merge with entering traffic, accelerating or decelerating if necessary to provide a gap for entering vehicles.

The following four countries are focused on in the report, Denmark, Germany, Netherlands and Spain. In Denmark, the on-ramp and motorway are separated by a broken line only at the beginning (three lines) whilst in the other three countries, the line marking continues for the entire merge length.

The report from Rysgaard and Nielsen (1995) describes a study which video recordings from 12 motorway on-ramps (three in each country), matched in terms of geometric features and traffic characteristics, were analysed to investigate a wide range of merge characteristics. Including:

- Ramp vehicle speed
- Freeway vehicle speed
- Speed differentials
- Number of entries in front and behind vehicles which arrived simultaneously
- Acceptable gap size
- Dangerous situations
- Driver interactions

According to Rysgaard and Nielsen (1995), comparisons of results obtained in Denmark (zip merging) and the other three countries revealed that:

- Merges in Denmark took place at similar speeds. Zip merging did not appear to impact upon the speed at which merges take place.
- Denmark had the lowest 85th percentile speed difference in situations where the ramp vehicle enters the motorway in front of a simultaneously arriving motorway vehicle. This has positive safety implications
- Fewer dangerous situations occurred in Denmark. Dangerous situations included ramp vehicles continuing on in the emergency lane (or shoulder), stopping at the end of the merge lane, or being involved in a serious conflict.

Overall the results obtained by Rysgaard and Nielsen (1995) seem to indicate that zip merging has some noteworthy advantages, at least in terms of the factors measured.

2.5.4 Driver behaviour and awareness

Probably the most fundamental factor contributing to the safety and efficiency on our roads is the human driving the vehicle. It is often left untouched in much of the research out there, due probably because of the complexity of the variables involved. This report is not offering to solve the complex nature of the human factor, instead, it is aimed more at highlighting the lack of driver education and confusion that exists on today's roads

Prendegast M, Kamper A and Reardon N (2013) Acknowledge that there is a need to increase awareness on road rules. They also explain that road user interactions highly indicate problems sharing the road because of this confusion amongst motorists.

In February 2013, the Centre for Road Safety launched the inaugural Road Rules Awareness Week. As part of road rules awareness week, the Centre for Road Safety developed NSW's first Top Ten Misunderstood Road Rules guide (Transport for NSW 2013b). Prendegast M, Kamper A and Reardon N (2013) explain that there was extensive media coverage throughout the week, including:

- 6 TV stories
- 29 print stories (Daily Telegraph, Sydney morning Herald)
- 56 Radio mentions
- An article also featured in NRMA's Open Road magazine

It is thought that confusion exists amongst motorists in NSW at zip merge locations. As zip merging in Australia has only been a recent development (since about 2000), one possible reason for this confusion is the lack of driver education and awareness regarding proper merge practices. The guide 'Top 10 misunderstood road rules in NSW' (Transport for NSW 2013b) aimed at familiarising NSW motorists about road rules that are believed to be forgotten about by many drivers. The guide provides illustrative examples of certain rules that drivers often disobey, as well as short video clips that are available on the RMS website.

Figure 2.12 – Top 10 misunderstood Road Rules in NSW (Transport for NSW 2013b)

Transport for NSW (2013b) stated that merging is amongst the top 10 misunderstood road rules. Examples of the correct merging procedures for both zip and standard merging are shown in the guide and have been reproduced in Figure 2.13 and Figure 2.14.

Figure 2.13 shows a zip merge, where the left lane that car (A) is travelling in finishes. The diagram shows car (A) in front of car (B) and Transport (2013) states 'Car B gives way to Car A'. In Figure 2.14, the situation is replicated, however this time there is linemarking continuing through the merge taper. Once again car (A) is in front of car (B) at the point of merge, only this time Transport (2013) states 'Car A gives way to car B'.

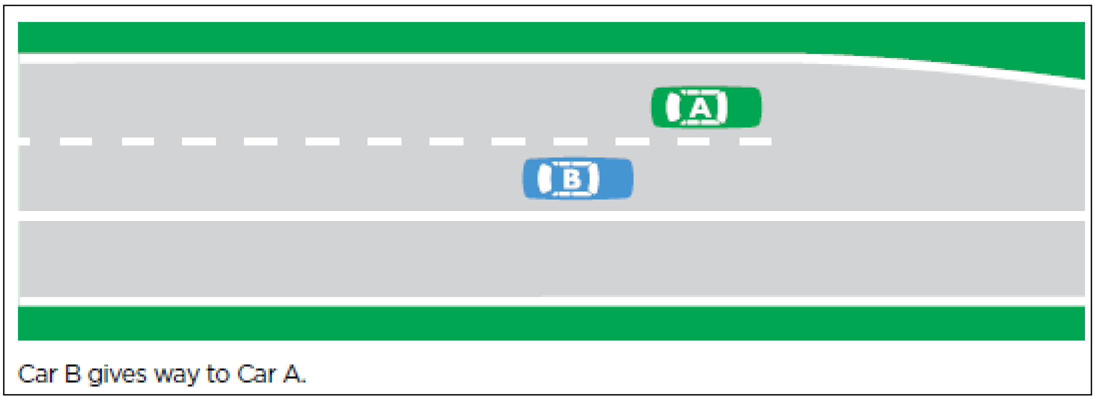


Figure 2.13 – Right of way at zip merges (Transport for NSW 2013b)

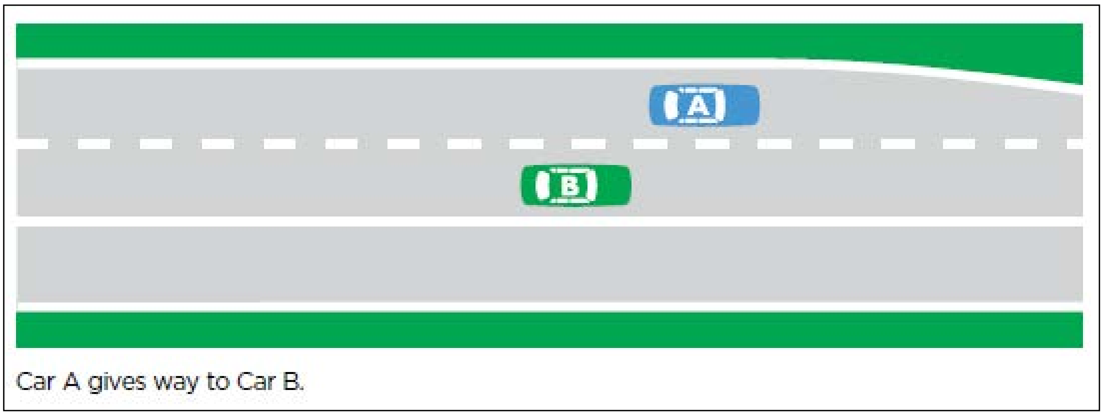


Figure 2.14 – Right of way at standard merges (Transport for NSW 2013b)

The occurrence of the merge situation in Figure 2.14 is believed to be one of the fundamental reasons why drivers have issues with merging (Prendegast M, Kamper A & Reardon N 2013). Consider the situation just like the one in Figure 2.14; if both vehicles are travelling at roughly the same speed then to successfully negotiate the upcoming merge, whilst obeying Australian road rules (rule 148, National Transport Commission (2012)), at least one of the following must happen:

- Vehicle A must slow down to let vehicle B get passed
- Vehicle B must speed up to get passed vehicle A

Prendegast M, Kamper A and Reardon N (2013) explain that motorists tend to exercise their right of way in a give-way merge situation, contributing to the issues faced by road users in NSW and Australia during merging.

New Zealand Transport Agency (NZTA) launched a "good manners" motorway campaign for Auckland. The campaign focuses on four (4) key messages for motorway drivers:

- Merging
- Changing lanes, and
- Not using mobile phones or texting while driving

All messages are encouraging drivers to employ safe driving practices by reinforcing 'motorway manners'. NZTA (2013) mentions the implementation of it's "merge like a zip" campaign, which was initiated for drivers to display on-ramps and other key areas requiring merging. NZTA (2013) says that the "Merge like a zip" campaign is an example of courteous driving that was aimed at reminding drivers to give way and allow others to enter the lane safely.

NZTA (2013) mentions that part of the push for driver awareness involved advertisements in magazines and newspapers articles, along with the installation of road signs along parts of New Zealand's road network. Two examples of the advertisement used is captured in Figure 2.15 below.

Figure 2.15 – Merge like a zip billboard advertisement (NZTA 2013)

2.5.5 Are merges a safety problem?

Cairney (1998) reported that in the South East Metropolitan Melbourne between 1994 and 1997, there were 37 merging and sideswipe crashes. Of these, eight (22%) were serious injury crashes and none were fatal crashes. It was estimated that an average of 14 casualty crashes per year occurred in Metropolitan Melbourne during any merge manoeuvre and that this constituted less than 1% of total casualty crashes in the region.

Cairney's (1998) study indicates that merging is not responsible for a large percentage of Melbourne's road toll and that, as such, significant investments into improving merge safety would need to be justified by other factors, such as efficiency.

In a study by Jing-Shiarn Wang and Knipling (1994), Lane Change/Merge (LCM) crashes in the United States in 1991 were calculated. their study shows that in 1991, there was a total of 6.11 Million crashes, of which there were approximately 244,000 police-reported LCM crashes, with 224 associated fatalities. Their findings are shown in Figure 2.16.

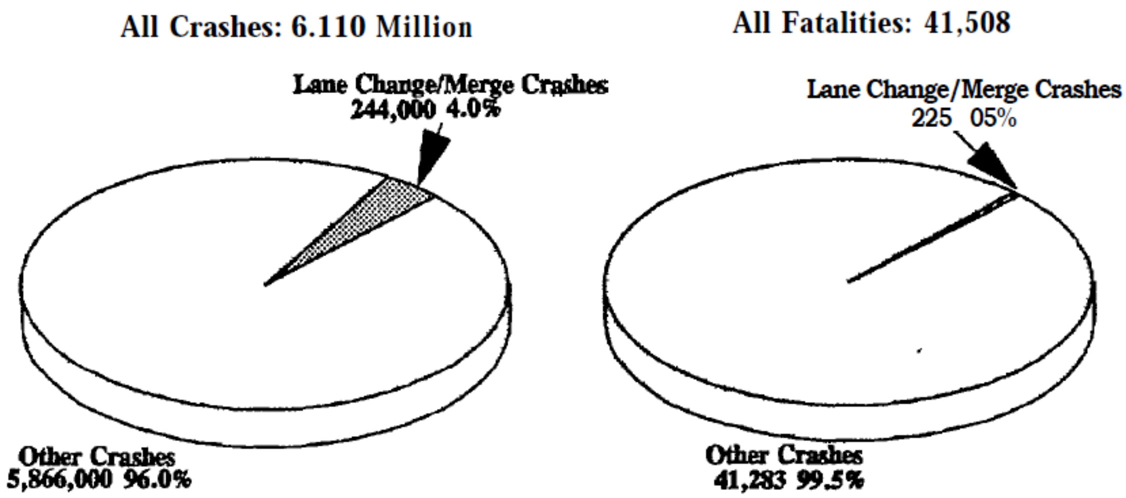


Figure 2.16 – Summary of LCM crashes in the US in 1991 (Jing-Shiarn Wang & Knipling 1994)

The results from Jing-Shiarn Wang and Knipling (1994) shows that LCM crashes accounted for approximately 4.0% of overall reported crashes. Although, only 0.5% of all fatalities occurred as a result of LCM crashes, this is still a significant figure.

2.5.6 Accident costs

Transport for NSW released a road safety strategy (Transport for NSW 2012), which show significant improvements on the road toll over the past 30 years. Transport for NSW (2012) said that 2011 had the lowest road toll since 1926 (364 fatalities). They also state that road crashes are still a leading cause of death aged one to 44 years in NSW, and they cost the community around $5.37 billion in 2011.

Transport for NSW (2013a) states that accident costs can be estimated based on two main approaches:

- Willingness to Pay (WTP) and
- Human Capital Cost

The willingness to Pay approach will be investigated in this report and is defined by Transport for NSW (2013a) as:

> *"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 the Stated Preference surveys where respondents are asked to choose hypothetical scenarios systematically varied in safety, travel time and cost. Economic models are specified and developed to statistically estimate the monetised valuation of safety."*

To estimate the crash cost values from the WTP approach in NSW, Roads and Traffic Authority commissioned PricewaterhouseCoopers (PwC) to undertake a study in 2008 (PwC 2008). PwC commissioned the Hensher Group to undertake stated preference surveys, and estimated the values of fatality risk, severe injury risk, injury risk and minor injury risk. The results were indexed to 2012/13 values and are shown in Table 2-5.

Transport for NSW (2013a) recommends these values be used in economic appraisals of transport policy, projects and programs.

Table 2-5 - Fatality and injury costs, WTP approach, 2012/13 (Transport for NSW 2013a)

Risk categories		Urban	Rural	Weighted Average
Costs per person				
Value of fatality risk reduction		$6,146,809	$6,742,550	$6,465,067
Serious injury risk reduction		$451,485	$628,776	$478,963
Other injury		$74,881	$106,815	$79,830
Where a breakdown of different types of crashes is not available for a project, injury risk reduction.		$107,916	$154,166	$115,344
Costs per crash				
Fatal crash	Average persons killed per crash	1.04	1.14	1.09
	Average number of persons injured per crash	0.54	0.85	0.73
	Cost per crash	$6,450,956	$7,817,548	$7,131,124
Injury crash	Average number of persons injured per crash	1.26	1.40	1.28
	Cost per crash	$135,974	$215,832	$147,640
Average cost of crash – Rural (used in REVS model)			$355,292	
Average cost of crash – Urban		$94,566		
Property damage only		$9,289	$9,289	$9,289

As stated by Transport for NSW (2013a), the crash costs in Table 2-5 are suitable in general economic appraisals. In road projects however, where the precise definition of crash type is known, more detailed safety analysis can be undertaken by using the accident costs shown in Table 2-6 (Andreassen 2001). These are grouped by RUM (Road User Movement) code as defined by the NSW Centre for Road Safety. A visual representation of the RUM codes can be found in Appendix C of this report.

Table 2-6 – Crash costs by crash type (Andreassen 2001)

Crash type group		Cost ($'000)	
RUM code	**Brief description**	**Urban**	**Rural**
Two vehicle type			
10,11 - 19	Intersection, from adjacent approaches	$61.9	$252.8
20, 50	Head-on	$176.4	$433.6
22 - 29	Opposing vehicles; turning	$62.4	$216.0
30 - 32	Rear end	$38.0	$105.8
33 - 35	Lane change	$49.2	$247.5
36 - 37	Parallel lanes; turning	$41.3	$186.9
40	U-turn	$55.6	$231.1
42, 47, 48	Vehicle leaving driveway	$44.7	$166.8
51, 52, 54	Overtaking, same direction	$62.4	$140.4
41, 60 – 63, 94	Hit parked vehicle	$60.6	$194.4
Average Two Vehicle Crash Cost		**$65.3**	**$217.5**
One Vehicle Types			
00 - 09	Pedestrian, crossing carriageway	$193.6	$517.1
64 – 66, 91	Permanent obstruction on carriageway	$100.8	$171.6
67	Hit animal	$51.6	$63.2
70, 72	Off carriageway, on straight	$81.4	$153.9
71, 73	Off carriageway, hit object	$108.6	$183.2
74	Out of control on straight	$90.1	$161.2
80, 82, 84, 86	Off carriageway, on curve	$92.0	$153.1
81, 83, 85, 87	Off carriageway, hit object	$119.8	$158.7
88	Out of control on curve	$82.8	$135.4
Average One Vehicle Crash Cost		**$102.3**	**$188.6**

Crashes types that are generally associated merging are rear end (RUM: 30-32) and lane change (RUM: 33-35) type crashes, which according to Table 2-6 are valued at $38,000 and $49,200 (Urban), $105,800 and $247,500 (Rural) respectively.

Transport for NSW published crash summaries for NSW in 2012 (Centre for Road Safety 2012). The total number of recorded crashes was 41,520 with 336 fatal crashes, 18,110 injury crashes and 23,074 non-casualty crashes. As previously mentioned, findings by Cairney (1998) reported that less than 1% of casualty crashes were directly associated with merging. If it were that merging made up approximately 1% of total casualty (injury or tow-away) crashes on NSW roads, this would give a figure of around 400 crashes annually as a result of merging.

To estimate the costs associated with merging in NSW, by taking the average values for both urban and rural, rear end and lane change crashes, times by the number of crashes as a result of merging, we get a figure of:

$110,125 x 400 = $ 44million

Although no literature was found for an exact figure (%) that zip merging could potentially reduce crashes by. If implementation and correct usage of zip merging (state-wide) reduced crash rates of 5%, this would be a saving of around $2million annually. Of course, to achieve this saving however, capital costs for the removal of linemarking, as well as signposting and re-sealing of road pavement would need to be outlaid.

2.6 Dynamic Late Merge System (DLMS) – Zipper Merge

For several years, Minnesota Department of Transport (Mn/DOT) has been using an electronic detection system on selected large construction projects. This dynamic late merge system is referred to as a "Zipper Merge" and is used for lane reductions on highways in construction zones. The strategy is reasonably simple, when a lane is closed in a construction zone (see Figure 2.17), motorists are encouraged to use both lanes until reaching a defined merge area (start of merge taper) and then alternate in a "Zipper" like fashion into the open lane.

Figure 2.17 – Zipper Merge system used in construction zones in the US (Mn/DOT 2014)

URS (2003) explains that there are two types of merging behaviour observed in advance of highway work zones:

> *"The first and most common is an early merge where drivers leave the closed lane in advance of the congestion queue. The second merge type is a late merge where drivers use all lanes to the physical merge point, this type is only observed where drivers are obstructed to do so."*

The objective of the project was to develop, test, and evaluate a traffic control system that dynamically incorporates the best aspects from both types of merging. The initial testing of the DLMS was conducted on US 10. Under predefined traffic conditions, Changeable Message Signs (CMS) were used to display lane-use instructions to drivers in the section of road preceding the lane closure. URS (2003) stated that the deployment of the DLMS shortened queue lengths by 35 percent, equalised lane usage near the taper point, however slightly reduced vehicle volume through the construction zone.

Further studies (Mn/DOT 2004) for the DLMS system were undertaken in 2004 with five distinct potential benefits outlined as a result of using this traffic control strategy. These potential benefits are stated by Mn/DOT (2004) as:

- **Shorten queue lengths before work zone:** By encouraging the use of both lanes in congested conditions.:
- **Increase traffic capacity through work zone:** Based on experience from previous studies, having a merging point at a defined location will increase the number of cars through the work zone.
- **Reduce aggressive driving:** If no other benefits are achieved, reducing the stress levels for drivers at the work zone could beneficial enough to warrant the use of the DLMS system.
- **Decrease the number of work zone related incident:** It is noted in the report that the length of a typical system will not provide enough data to definitively conclude whether or not the DLMS decreased the incident rate. However, the system has the potential to eliminate many dangerous situations that result in collisions.
- **Reduce travel times**

Mn/DOT's Dynamic Late Merge System (DLMS) was deployed at three different locations around the Minneapolis metropolitan area during the summer of 2004. A static CMS sign is shown in Figure 2.18, along with a typical layout for the DLMS in Figure 2.19.

Figure 2.18 – Static Changeable Message Sign (Mn/DOT 2004)

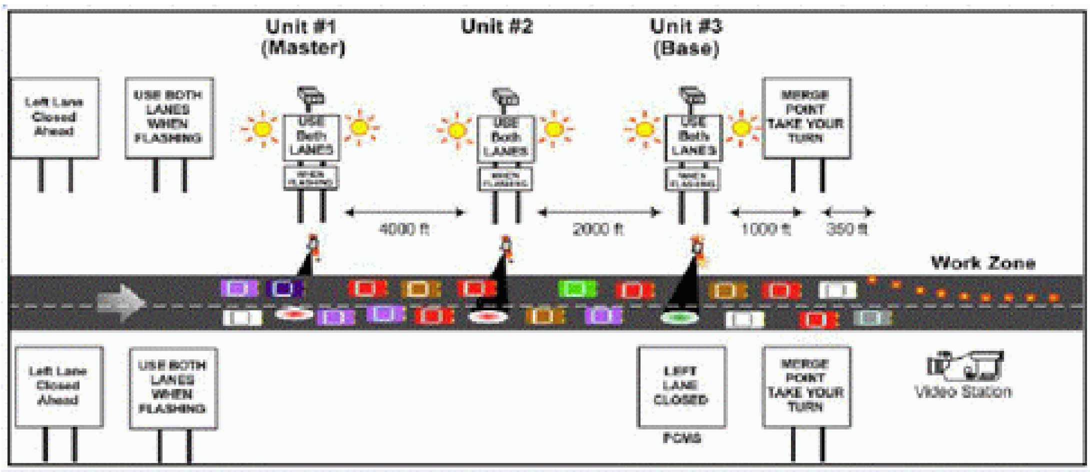


Figure 2.19 – Dynamic Late Merge System (Mn/DOT 2004)

It can be seen from Figure 2.19, the DLMS was comprised of a set of portable CMS's and three Remote Traffic Microwave Sensor's (RTMS) are added to the static traffic control devices utilised at construction zones with lane closures.

Mn/DOT (2004) found that the percentage of drivers utilising the discontinuous lane increased dramatically when the CMS's were activated. It was also noted that vehicles were visually observed utilising the majority of both lanes during congestion. This resulted in a queue of minimum length, however, it was reported that there was still a small number of drivers who are unwilling to use both lanes, resulting in a long single lane queue and observed blocking vehicles from filling the discontinuous lane. Mn/DOT (2004) reported that maximum volume throughput within the single lane construction closure at deployment locations was nearly identical.

3. METHODOLOGY

3.1 Introduction

To evaluate the possible safety and efficiency benefits with the introduction of zip merge treatments in NSW, an on-site analysis was needed. The idea behind this method was to record driver behaviour at specific merge sites in an attempt to understand how they are functioning, which can then provide further insight into the pros and cons of zip merge treatments.

To become familiar with the necessary elements that are present at merges (in particular zip-merges), an extensive literature review was undertaken. This literature provided a solid background on the standards and critical components, which in turn were used in determining appropriate techniques for data collection.

3.2 Data collection

This project required data to be collected from site investigations. The data was collected using the following method:

1. Determine the critical peak hour traffic volumes at each of the chosen sites by utilising RMS traffic data.
2. Attend the chosen sites when traffic volumes are low to determine ideal locations for setting up a video camera. Ideally, the location should be able to view the entire merge length, but positioned in a safe distance away from the road carriageway.
3. Arrive at each site just before peak travel times, set up the camera and record the peak hour traffic flow.
4. Make notes of any irregular actions performed by drivers throughout the duration of the inspection, e.g. Braking during merging, accidents, near misses, swerving, or vehicles forced to run out onto the shoulder.
5. Review the recorded footage from each site and provide further analysis from observing driver behaviours and characteristics.

3.3 Site Selection

Six (6) sites have been selected for investigation. These sites have been chosen because they cover a wide range of merge situations, which are thought will provide useful information through the process of data collection. Some key features that have lead to the selection of the chosen sites are:

- A range of speed zones (60, 70, 80, 90)
- High AADT counts, which have provided large number of driver interactions
- Lane drops and acceleration lanes (where speeds are similar between lanes)
- Sites that have been changed from 'lane change' merges to zip merges (assisting in the analysis of recorded crash data)

The various speed zones have been chosen to shed some light on driver behaviour in different speed environments. A higher AADT will mean greater driver interactions throughout the chosen merge sites, resulting in a larger data set and a higher reliability of data.

A quick summary of the merge sites, and conditions for each of the chosen sites can be found in Table 3-1. Included in Table 3-1 is the road name, location, posted speed and type of merge. Figure 3.1 shows the locations of each site.

Table 3-1 – Summary of zip merge sites

SITE No.	ROAD NAME	LOCATION	POSTED SPEED (km/h)	AADT	TYPE OF MERGE
1	Cormorant road	Kooragang	80	15868	Lane reduction
2	Toronto Road	Woodrising	80	14293	Lane reduction
3	New England Highway	Harpers Hill	90	9588	Acceleration lane
4	Hillsborough Road	Warners Bay	70	12924	Acceleration lane
5	Weakleys Drive	Beresfield	60	9904	Lane reduction
6	Newcastle road	Cameron Park	80	15413	Lane reduction

Looking at table Table 3-1, it should be noted that each site deals with high AADT values. Four out of the six sites have an AADT of over 10,000, two of which are over 15,000. Mentioned earlier in this report (section 2.5.1), Nemeth and Rouphail (1983) explained that disruptions in traffic flow can occur when a threshold of approximately 1250 vehicles per hour for a two lane merge situation. It is believed that traffic flow will be affected by these high AADT values (shown in Table 3-1) at a number of the investigated sites.

3.3.1 Overview of site locations

Each of these sites are displayed on a large aerial photograph of the hunter region of NSW shown below in Figure 3.1.

Figure 3.1 - Overview of site locations

3.3.2 Site 1 – Cormorant Road, Kooragang

Background

Site 1 is an 80km/h located in the industrial area of Kooragang, an important link carrying traffic from the bay and surrounding areas into Newcastle. Shown below in Figure 3.2 are photographs taken at the site.

Figure 3.2 – Photographs of site 1 – Cormorant Road

Details of site

Table 3-2 provides a summary of the site

Table 3-2 – Site 1 details

Location	Kooragang Island
Merge type	Lane reduction
Average Annual Daily Traffic (AADT)	15868 (Oct-10)
Merge taper length	Above minimum (>130m)
Signposting	Conforms with Standard
Sight distance	Meets requirements
Longitudinal grade at merge	Flat (<2%)

Geometric Layout

The geometric layout and merge taper length of the site is captured in Figure 3.3.

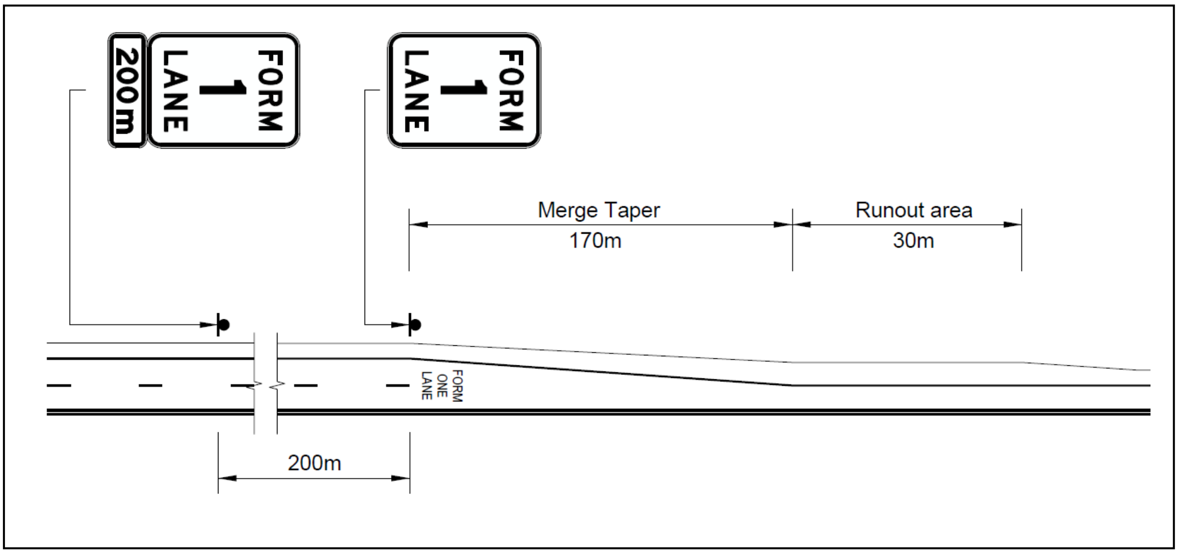


Figure 3.3 – Site 1 – Cormorant Road, Kooragang – merge geometry

It can be seen in Figure 3.3 that there is advanced signage and additional 'FORM ONE LANE' markings along with a merge taper much greater than the minimum of 130m shown in Figure 3.3. Along with the desirable signage and markings, the site is flat and has great visibility along the length of the road. All these factors contribute to making this an ideal merge, and results for this site should compliment that.

3.3.3 Site 2 – Toronto Road, Woodrising

Background

This section of Toronto road is a busy 80km/h located in the outer suburbs of Newcastle. Toronto road is a two-lane two-way main road with continual upgrading to help ease congestion. The section where the zip merge is located has been constructed at the same time as an upgrade to an intersection (traffic lights) with enterprise drive. To provide additional capacity, a second through lane develops 150m prior to the traffic signals and reduces back to one lane approximately 300m after. Photographs of the site while undertaking the site visit are found in Figure 3.4.

Figure 3.4 – Photographs of site 2 – Toronto Road

Looking at Figure 3.4 and , it can be seen that there are warning signs 'W4-9' and 'W8-15' located in advance of the merge. This signposting placement is incorrect for this type of merge. The is a good example of what Zhong and Chee (2009) stated, with a large occurrence of signposting deficiencies at merge locations.

Details of site

Table 3-3 provides a summary of the site

Table 3-3 – Site 2 details

Location	Woodrising
Merge type	Lane reduction
Average Annual Daily Traffic (AADT)	14293 (Feb-13)
Merge taper length	Above minimum (> 130m)
Signposting	Does not conform to standard
Sight distance	Meets requirements
Longitudinal grade at merge	Uphill (3-5%)

Geometric Layout

The geometric layout and merge taper length of the site is captured in Figure 3.5

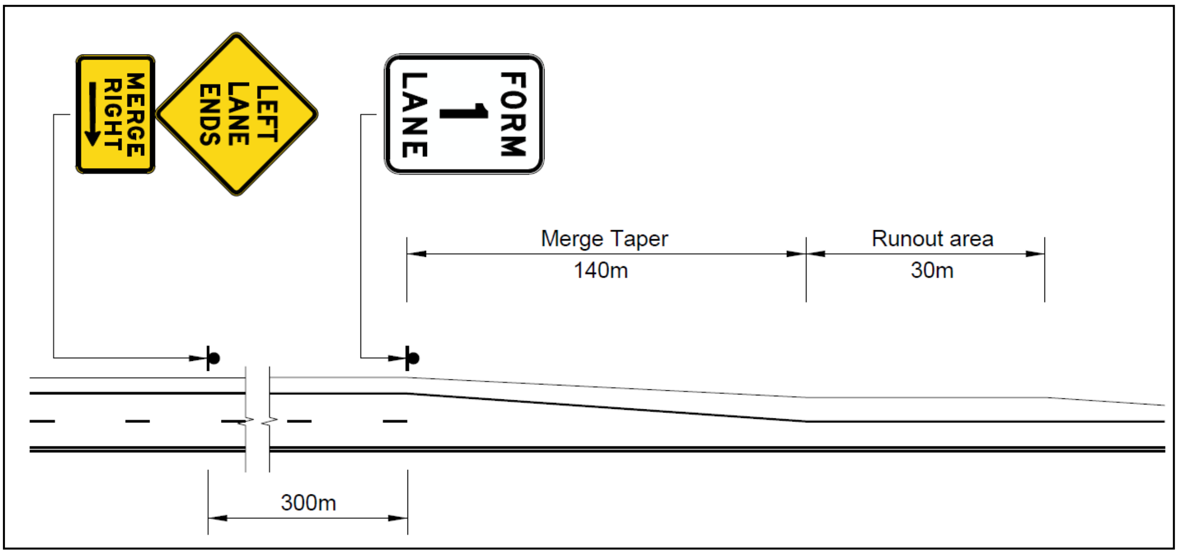


Figure 3.5 – Site 2 – Toronto Road – Merge Geometry

3.3.4 Site 3 – New England Highway, Harpers Hill

Background

The New England Highway running through Harpers Hill is a high speed rural road consisting of undulating terrain about 40km North-west of Newcastle. A number of crashes at a seagull intersection over a number of years 1km before an existing merge led to an upgrade of the intersection, which gave the traffic from the minor road at the intersection it's own lane acceleration lane (in the offside lane) for approximately 1km before having the major traffic stream merge across as shown in Figure 3.7.

Figure 3.6 – Photographs of site 3 - New England Highway

Details of site

Table 3-4 provides a summary of the site

Table 3-4 – Site 3 details

Location	Harpers Hill
Merge type	Lane reduction
Average Annual Daily Traffic (AADT)	9588 (Jun-13)
Merge taper length	Above minimum (>150m)
Signposting	Conforms to standard
Sight distance	Non-conforming (Full merge length not visible)
Longitudinal grade at merge	Flattening over a crest (3-5%)

Note that the sight distance in Table 3-4 is listed as sub-standard. The sight distance required at merge locations has been researched from road design standards and basically states that the entire merge taper length must be visible throughout the merge manoeuvre. In this situation, the end of the merge taper is located beyond a crest curve and sight is restricted throughout, therefore is deemed non-conforming sight distance.

Geometric Layout

The geometric layout and merge taper length of the site is captured in Figure 3.7.

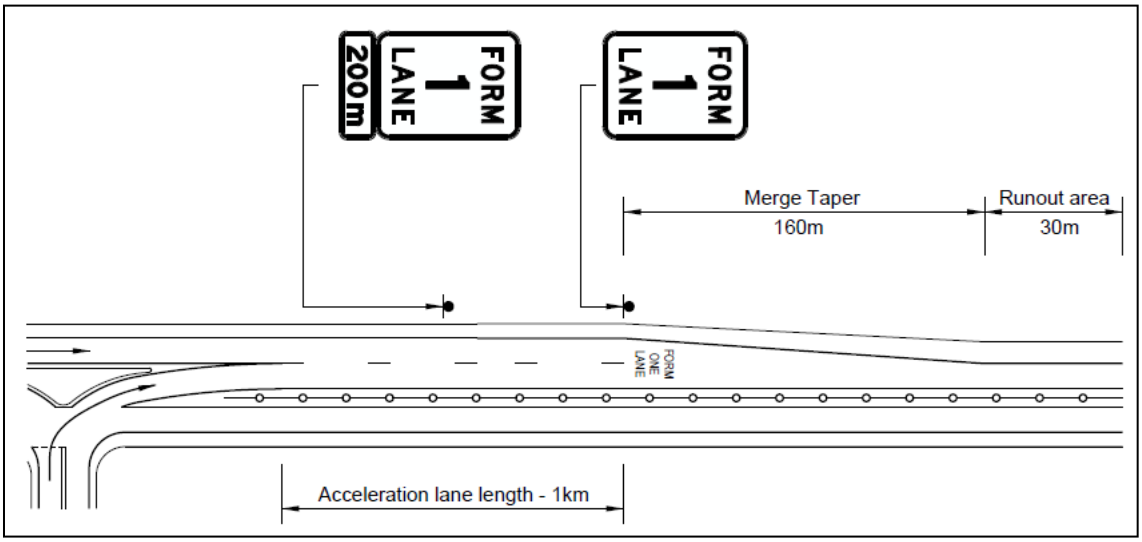


Figure 3.7 – Site 3 – New England Highway – merge geometry

It can be seen in Figure 3.7 that the through traffic along the New England Highway is already positioned into the nearside lane that is being reduced. The acceleration lane that has been given for the vehicles coming onto the New England Highway from the minor leg (Allendale Rd) ends up being the continuing lane.

Having the acceleration lane from the minor road as the continuing lane creates an interesting situation where the majority of the traffic will be in the lane being reduced and will be forced to merge.

3.3.5 Site 4 – Hillsborough Road, Warners bay

Background

Hillsborough road is a 70km/h main road, with an AADT of 12924 (Nov-08). The acceleration lane that merges onto Hillsborough road comes off Crockett Street, which was upgraded into a left slip lane (previously a give-way) as traffic numbers from Crockett Street are quite significant and it was difficult to find gaps to enter Hillsborough Road.

Figure 3.8 – Photographs of site 4 - Hillsborough Road

Details of site

It can be seen in Figure 3.8 (right) that the G9-15 (Form 1 Lane) sign is not positioned at the start of the merge taper. Instead, there is a guidepost located at the start of the merge taper and the G9-15 sign has been installed approximately 10 meters further along. This is a typical example of a lack of attention-to-detail with signposting. Table 3-5 provides a summary of the site.

Table 3-5 – Site 4 details

Location	Warners Bay
Merge type	Lane reduction
Average Annual Daily Traffic (AADT)	12924 (Nov-08)
Merge taper length	Right on the minimum length required (=70m)
Signposting	Does not conform (only includes 1 x G9-15)
Sight distance	Meets requirements
Longitudinal grade	Downgrade (3-5%)

Geometric Layout

The geometric layout and merge taper length of the site is captured in Figure 3.9.

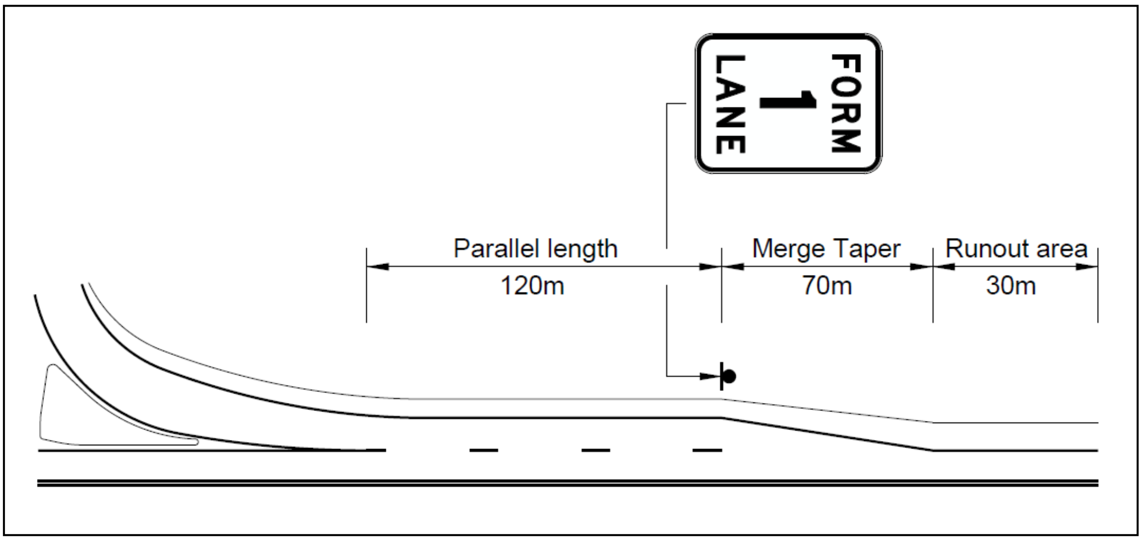


Figure 3.9 – Geometry of site 4 – Hillsborough Road

(Austroads (2010b)) states in table 5.4 that the acceleration length for cars for 70km/h including the merge taper needs to be a minimum of 150m where the entry speed of the curve is 20km/h. It can be seen from Figure 3.9 that the acceleration lane runs parallel with the through traffic lane for 120m before the start of the 70m length of taper, therefore this length is adequate.

3.3.6 Site 5 – Weakleys Drive, Beresfield

Background

Site 3 is Weakleys Drive, which is a 60km/hr road in an industrial area that connects traffic wanting to head south off the New England Highway with the start of the M1 Motorway, Beresfield. Recent population increase as well as industrial development has meant an upgrade to the two-lane two-way road. This upgrade has seen an extended length of dual lanes for southbound traffic after exiting the New England Highway.

Figure 3.10 – Photographs of site 5 – Weakleys Drive

Details of site

Table 3-6 provides a summary of the site

Table 3-6 – Site 5 details

Location	Kooragang Island
Merge type	Lane reduction
Average Annual Daily Traffic (AADT)	9904 (Mar-14)
Merge taper length	Right on the minimum length (=60m)
Signposting	Conforms to standard
Sight distance	Meets requirements
Longitudinal Grade (%)	Downhill (<3-5%)

Geometric Layout

The geometric layout and merge taper length of the site is captured in

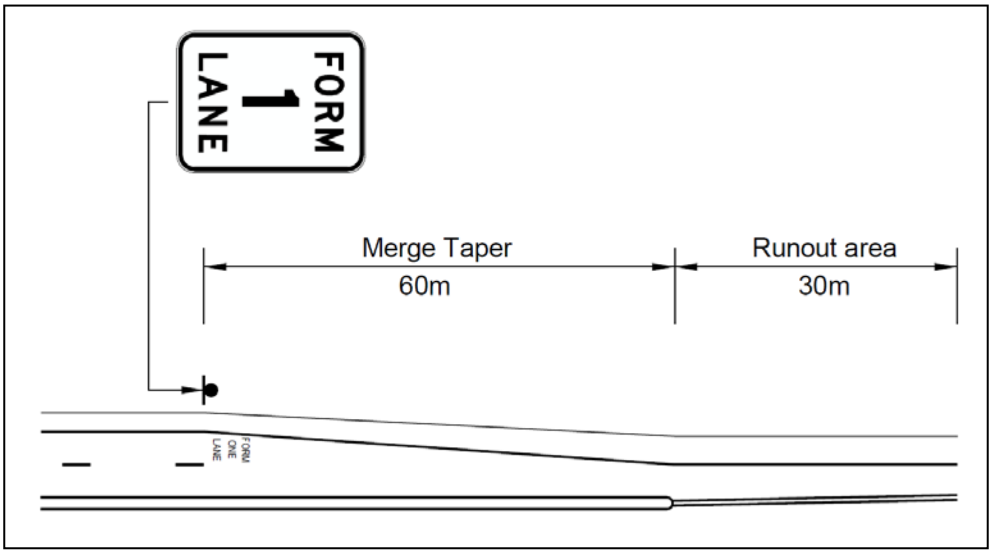


Figure 3.11 – Site 5 – Weakleys Drive – merge geometry

It can be seen in Figure 3.10 the addition of 'FORM ONE LANE' markings have been used for added driver awareness, however note that the markings have been installed incorrectly. They are aligned with the nearside lane, the correct position is in the middle of the two lanes.

3.3.7 Site 6 – Newcastle Road, Cameron Park

Background

This merge is on the exit leg of a recently constructed traffic signal site at Cameron Park. The intersection warranted traffic signals for the increase capacity needed for the opening of the Hunter Expressway (HEX) in early 2014. The signals are located right after the junction of the M1 Motorway and HEX. There is three through lanes heading into Newcastle which drops back to two about 300 meters after the signals. It is an interesting site as it is a major traffic junction for vehicles in all directions heading to and from Newcastle. Images taken whilst on site are captured in Figure 3.12.

Figure 3.12 – photographs of site 6 – Newcastle Road

Details of site

A summary of site 6 is listed below in Table 3-7.

Table 3-7 – Site 6 details

Location	Cameron Park
Merge type	Lane reduction
Average Annual Daily Traffic (AADT)	15413 (Mar-14)
Merge taper length	Above minimum (>130m)
Signposting	Conforms to Standard
Site distance	Meets requirements
Terrain	Flat (<2%)

Geometric Layout

The geometric layout and merge taper length of the site is captured in Figure 3.13

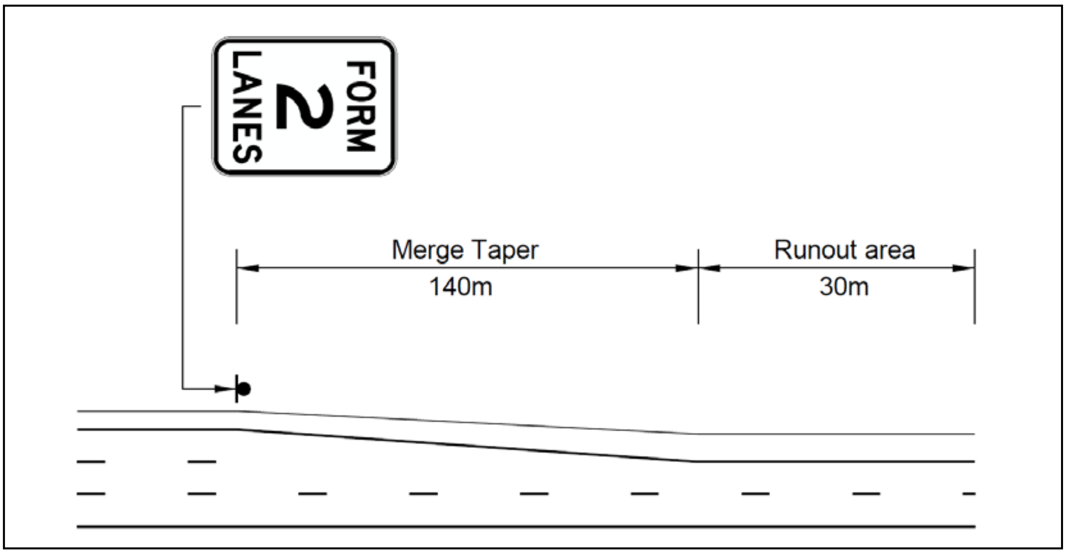


Figure 3.13 – Site 6 – Newcastle Road – merge geometry

Looking at Figure 3.13, it can be seen that for this site, the lane reduction is from three lanes down to two. This zip merge situation is not very common in the Hunter region of NSW, the extra through lane that is present in this location adds an extra dynamic to the data capture in this report.

3.4 Site observation point

The camera location for the observation in all sites were similar and is shown below in Figure 3.14. This location was considered ideal and was chosen for a number of reasons:

- The full extent of the merge is visible, including the runout area and approximately 30-50m before the merge starts.
- The location is considered safe, setting up a camera beyond the road shoulder and well clear of traffic.
- Brake lights and blinkers are both visible, which are key factors in determining the results.

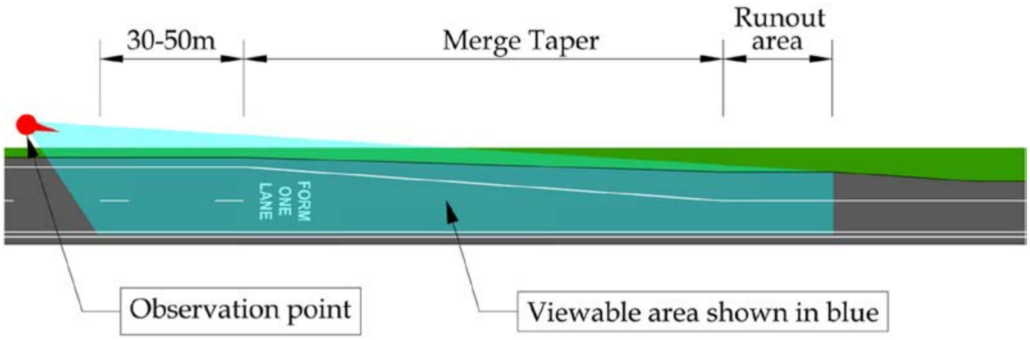


Figure 3.14 - Observation point for data capture

The area shaded in blue in Figure 3.14 is requires full visibility for data capture and is critical to the analysis and outcome. The length 30-50m before the merge is important as it will inform of typical vehicle behaviour approaching the merge. The length after the merge (runout area) will provide information on the vehicle behaviour directly after the merge.

4. ANALYSIS

4.1 Analysis of the data

The data collected from each site was entered into Excel spread sheets which have been used to tabulate the results for calculations and graphing. The data captured at the individual sites can be found in Appendix B. This data has been combined to give an overall understanding of how zip merges are performing in the Hunter Region of NSW. This combined analysis is found in section 4.2. Some of the noteworthy elements found in some of the individual sites are mentioned in the combined analysis.

4.2 Combined observation analysis

The merge manoeuvres observed were at six sites in the Hunter Valley, New South Wales. The footage taken whilst inspecting each site has been reviewed and findings listed in an Excel spreadsheet (found in Appendix B). The key findings calculated for each site have been combined. These combined results include:

- Traffic Volumes and total number of merges recorded
- Location where vehicles were merging
- Total number of vehicles that used brakes throughout the merge
- Blinker usage throughout the merge

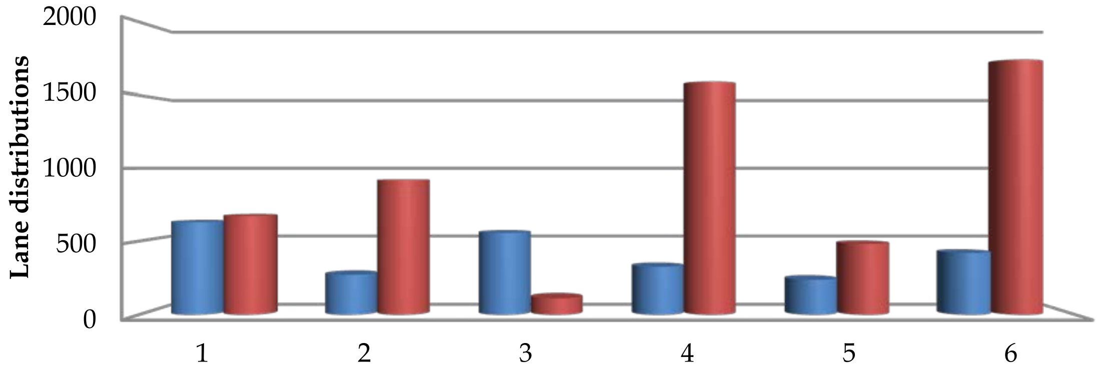
4.2.1 Traffic volumes and total number of merges recorded

In order to gain a good understanding of how zip merges were operating at each site, the number of merging vehicles were compared against the number of through vehicles. This comparison is shown in Table 4-1.

Table 4-1 –Summary of traffic volumes

Site No.	Total number of vehicles observed (vph)	Vehicles recorded in lane being reduced	Vehicles recorded in continuing lane	Percentage of vehicles in merge lane (%)
1	1303	630	673	48.3
2	1194	274	920	22.9
3	670	557	113	83.1
4	1920	330	1590	17.2
5	723	240	483	33.2
6	2166	425	1741	19.6

In order to gain a better understanding of the lane utilisation, a visual representation (Figure 4.1) has been added below.



	1	2	3	4	5	6
merging	630	274	557	330	240	425
continuing	673	920	113	1590	483	1741

Figure 4.1 – Lane utilisation at selected sites

From Figure 4.1, it can be seen that all the sites except site 3 had less than 50% of the traffic distribution in the merge lane. The large percentage of vehicles in the merge lane at site 3 is not unexpected. The reason for this is the through traffic along the New England Highway became the left side lane when an added lane from a minor leg joined and became the right side (through) lane.

Also, note that three of the six sites observed more than 1250 vph, which is regarded as the threshold before disruptions to traffic occur during merging (Nemeth & Rouphail 1983).

4.2.2 Point where vehicles merged

As part of the investigation, the point where vehicles are predominately merging are of interest. These points are defined as:

- Before the merge taper
- Inside the merge taper
- After the merge taper

Ideally, vehicles would want to utilise the full extent of the merge taper, thus allowing a smooth and consistent transition across into the forward position in the through lane, also minimising the angle to adjacent vehicles. The three points of merge that have been recorded in the site investigations are shown below in Figure 4.2. It should be noted that seen there is no clear line where a vehicle starts to merge, results are somewhat subjective. For example, if a car started to shift across the lane before the start of the taper, and completed the shift before halfway along the taper, it was classed as an 'early' merge.

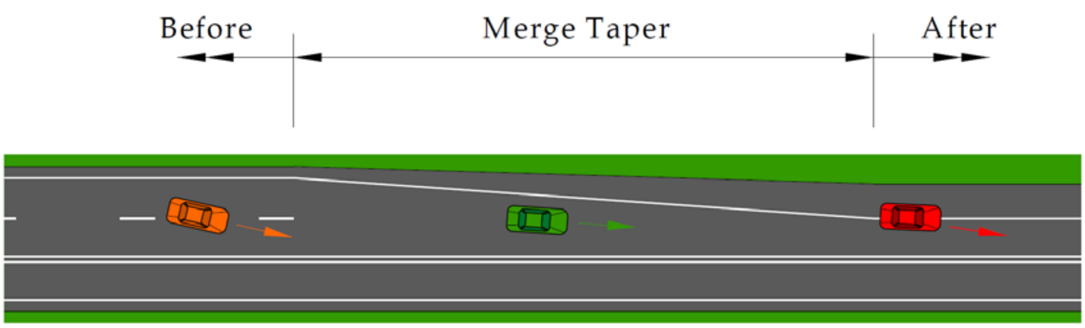


Figure 4.2 – Point where merging can occur

In Figure 4.2, the three merge points can easily be seen with the separate points being associated with different colours. The colours are as follows:

- Orange (discouraged) – Representing early merging, where vehicles have merged or are beginning to move across where there is still linemarking present, which then becomes a lane change.
- Green (desirable) – Is having the vehicle shift across within the merge taper, resulting in higher levels of safety and efficiency during periods of heavy congestion.

- Red (Undesirable) – This represents a driver that has failed to merge inside the merge taper, and is travelling some distance in the road shoulder before being able to position itself safely in the lane.

The summary of vehicles observed at each of the sites has been listed below, in Table 4-2.

Table 4-2 – Points where vehicles were observed to merge

Site No.	Point of merge relative to the merge taper						Total no. of merges
	Before		Within		After		
	No.	(%)	No.	(%)	No.	(%)	
1	54	8.6	575	91.3	1	0.2	630
2	190	69.3	84	30.7	0	0.0	274
3	11	2.0	546	98.0	0	0.0	557
4	235	71.2	93	28.2	2	0.6	330
5	18	7.5	222	92.5	0	0.0	240
6	248	58.4	176	41.4	1	0.2	425
Total	756	30.8	169.	69.1		0.2	2456

Table 4-2 shows that, overall most merge manoeuvres occur at either the middle or the end of the merge area. A visual representation of the observed point of merge is shown below in Figure 4.3.

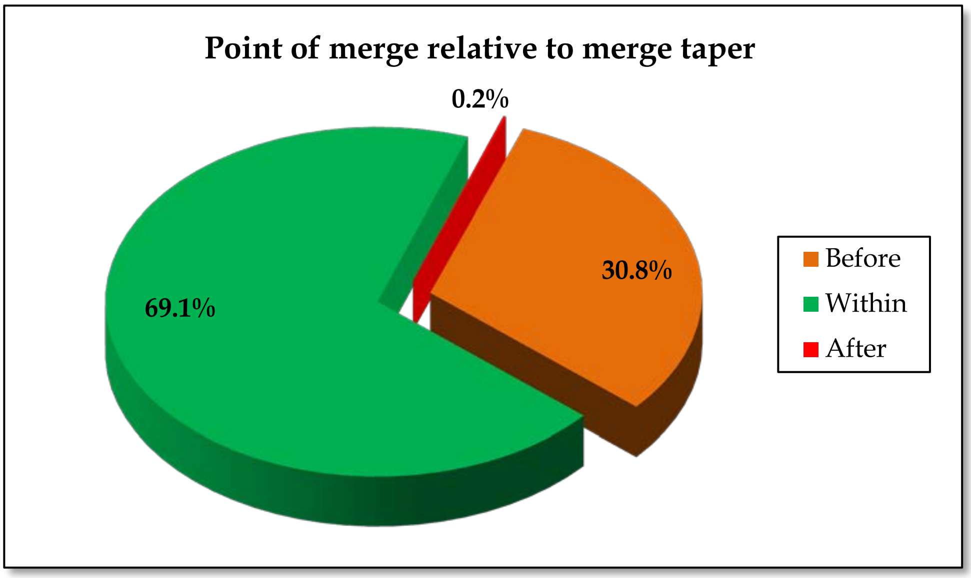


Figure 4.3 –Observed merging location

Figure 4.3 shows the average percentages of where vehicle were observed to merge. An average of approximately 70% of vehicles were merging in the desirable location, utilising the merge length. However, during site observations it was noticed that three out of the six sites had a much high percentage of vehicles merging early. Two of the sites that experienced a high rate of early merging were sites where the merge was located just after a set of traffic signals. The third site that produced high rates of early merging vehicles was the acceleration lane along Hillsborough Road (Site 4). This site recorded more than 1900 vph, 670 (35%) vehicles more than the 1250 vph threshold. Also, only 17% of vehicles were observed in the merge lane.

To highlight the large difference between the location of where vehicles were merging, sites that experienced a large percentage of early merges (2, 4 & 6) were compared against sites found to be performing well (sites 1, 3 & 5). These are shown in Figure 4.4 and Figure 4.5 respectively.

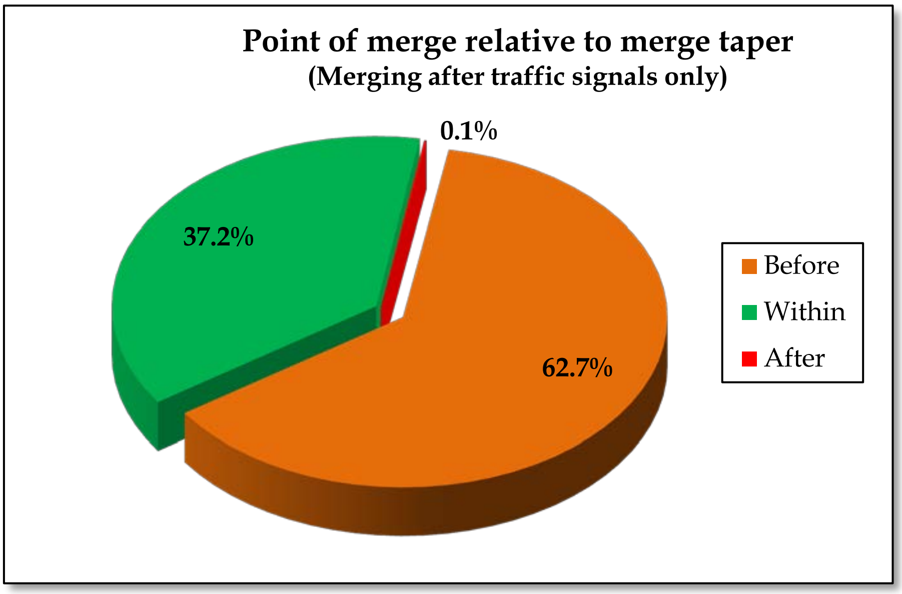


Figure 4.4 – Observed merging location (after signal zip merges only)

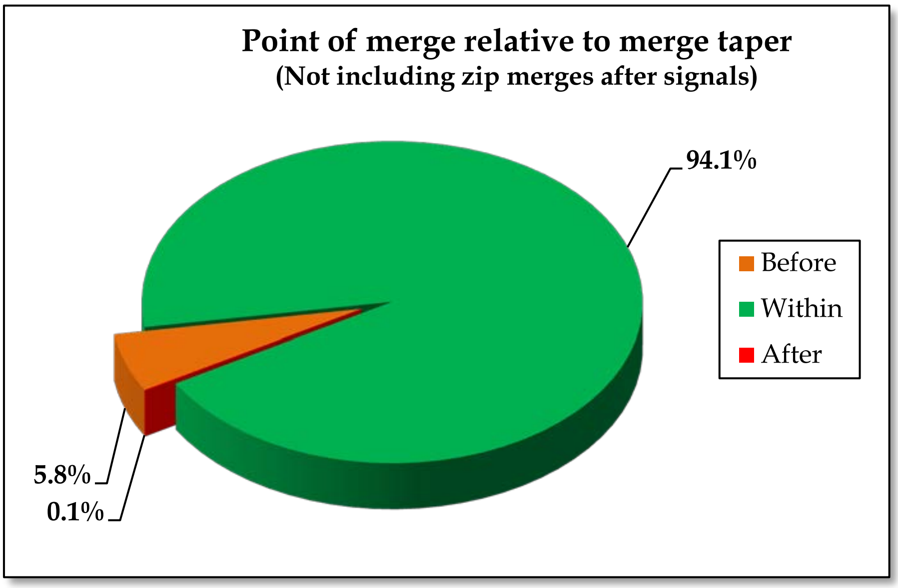


Figure 4.5 – Observed merging location (Not including zip merges after signals)

It can be seen in Figure 4.4 and Figure 4.5 that there is quite a substantial difference where vehicles were merging. Figure 4.4, which includes zip merge sites directly after traffic signals, shows that over 60% of vehicles were merging early. Vehicles at these sites were observed merging as soon as gaps appeared. Although it does not necessarily represent a safety concern, it does show that the proper zip merge technique was not adopted.

Figure 4.5 includes the locations motorists where observed merging at general lane reductions. What is meant by 'general' is that motorists would travel for a substantial amount of time before one of the lanes were reduced. At these locations, over 94% of vehicles merge within the taper, utilising the merge.

4.2.3 Total number of vehicles braking throughout the merge

Braking was another component of driver behaviour of interest in this report. The reason for this is that braking can highlight any irregular behaviours. For example, if there were large speed differences amongst vehicles approaching a merge, heavy braking would be expected as motorists attempted to adjust their speed.

The number of vehicles that used brake on approach and throughout the merge were calculated and are listed below in Figure 4.4.

Table 4-3 – Brake usage throughout merge

Site No.	Used brakes	
	Number (No.)	Percentage (%)
1	18	1.4
2	37	3.1
3	10	1.5
4	43	2.2
5	16	2.2
6	42	1.9

The occurrence of braking witnessed at zip merge sites (Table 4-3) was quite low, generally between 1 and 3 %. During site investigations, it was also noticed that vehicles that used brakes during merging were mainly adjusting their speed to vehicle beside them. This was observed mainly in advance of the approaching merge.

4.2.4 Blinker usage throughout the merge

Blinker usage throughout zip merges is also of interest. The National Transport Commission (2012) state that in a zip merge (rule 149) there is no linemarking from the point where two lanes become one, and therefore is not regarded as a lane change. However, the National Transport Commission (2012) mentions that regardless of whether it's a zip merge or a lane change, the merging driver should still use indicators to signal their intention.

Table 4-4 – Blinker Usage

Site	Used blinker	
	Number (No.)	Percentage (%)
1	102	16.2
2	165	60.2
3	123	22.1
4	264	80.0
5	56	23.3
6	330	77.6

Looking at the results in Table 4-4, it can be seen that there is quite a large spread for vehicles using blinkers throughout zip merges. To give a better understanding of blinker usage, a graph showing percentages of blinker usage at each site is shown below in Figure 4.6.

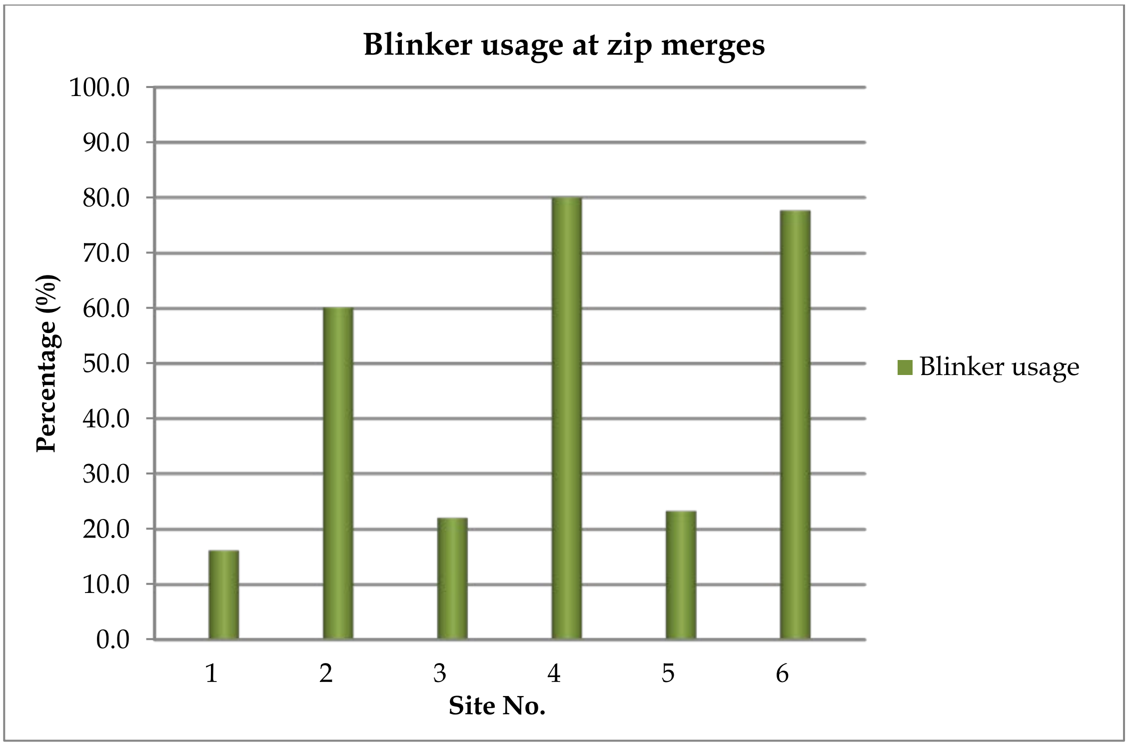


Figure 4.6 – Graph showing Blinker usage (%) recorded at zip merge sites

It can be seen that there is a much higher percentage of motorists indicating during merging at sites 2, 4 and 6. Sites 2, 4 and 6 also showed

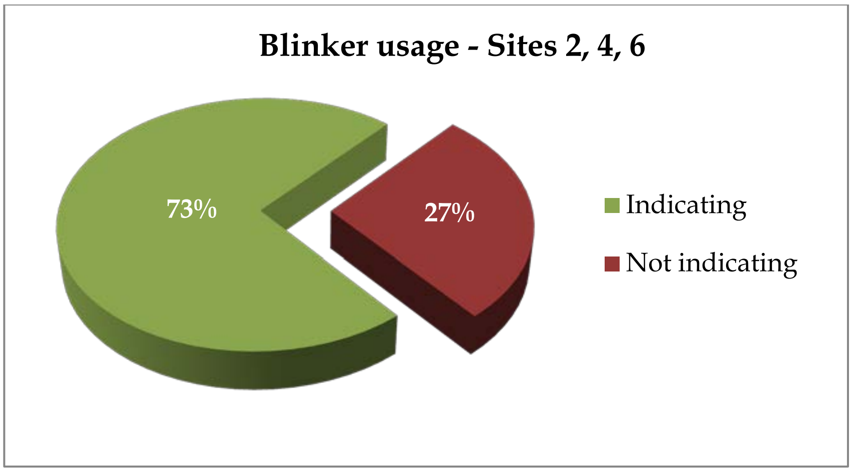


Figure 4.7 – Blinker usage at merge sites 2, 4 & 6

The pie chart above (Figure 4.7) shows a high number of motorists indicating at zip merge sites 2, 4 and 6. These are the sites that a large percentage (>60%) of vehicles were observed changing lanes before the merge taper.

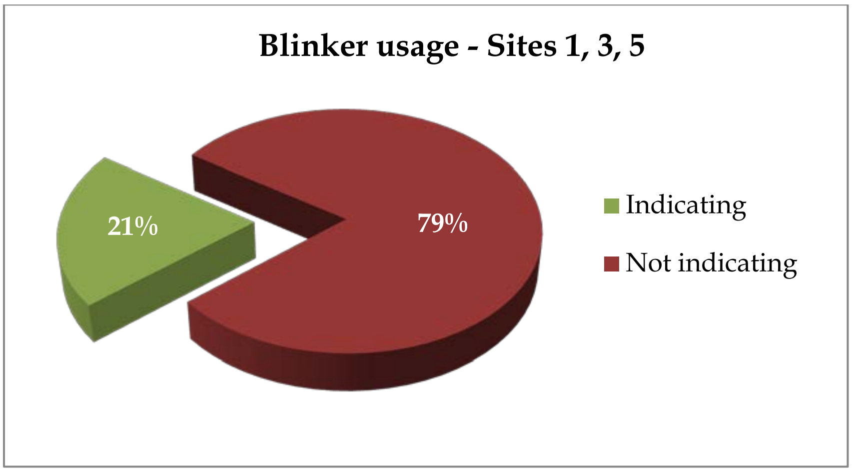


Figure 4.8 – Blinker usage at merge sites 1, 3 & 5

Figure 4.8 shows that only about 1 in 5 vehicles were indicating throughout the merge manoeuvre at sites 1, 3 and 5. Yet, at these sites, drivers were observed utilising more of the merge area, and displaying good driver behaviour:

- Adjusting speeds to match adjacent cars on approach to the merge
- Being courteous towards other drivers and allowing them in front

Therefore, although drivers were not indicating their intentions, other drivers seemed to be well aware of the merge situation and acted accordingly.

4.3 Crash Statistics

Three out of the six sites investigated have also been used in a before-and-after crash analysis. This was due to fact that three out of the six sites chosen in this investigation were converted from standard give-way merges into zip merges through recent (more than 2 years) road upgrades. Road upgrades included re-surfacing works in the vicinity of the merge, as well as minor safety improvements along other parts of the road.

The ability to perform crash analyses of these sites was through gaining access into CrashLink through undergoing classroom training with RMS. CrashLink is a reporting system that provides information on reported crashes in New South Wales, conforming to national guidelines for reporting and classifying road vehicle crashes.

4.3.1 Site 1 – Cormorant Road, Kooragang

Crash statistics are listed in Table Table 4-5 for the before and after case at Cormorant Road. The corresponding years that the crash statistics represent are:

- Before – 2009 to 2011
- After – 2012 to 2014

Table 4-5 – Crash summary for Site 1 – Cormorant Road, Kooragang

	Fatal	Injury	Non-Casualty	Total recorded crashes
Before	0	2	2	4
After	0	1	0	1

The crashes shown in Table 4-5 show a 75% reduction in crash rates. Between the years of 2009 and 2011 there were four crashes, two of those resulted in injury. The Detailed crash report obtained from Crashlink show that three of those crashes were of rear end crashes. This is a common crash type associated with merging.

Since the zip merge has been implemented (late 2011), there has only been one reported crash between the years 2012-2014. The detailed crash reports for both cases are included in appendix C

4.3.2 Site 2 – Toronto Road, Woodrising

Crash statistics for Toronto road are listed in Table Table 4-6. The corresponding years that the crash statistics represent are:

- Before – 2009 to 2011
- After – 2013 to 2014

Table 4-6 – Crash summary for Site 2 – Toronto Road, Woodrising

	Fatal	Injury	Non-Casualty	Total recorded crashes
Before	0	2	0	2
After	0	1	0	1

The crashes shown in Table 4-6 Table 4-5 show a 50% reduction in crash rates. Between the years of 2009 and 2011 there were two crashes resulting in injury. Since the zip merge has been implemented (2012), there has been one reported crash between the years 2013-2014. The detailed crash reports for the before and after cases can be found in appendix C.

4.3.3 Site 3 – New England Highway, Harpers Hill

Crash statistics for the New England Highway are listed in Table 4-7. The corresponding years that the crash statistics represent are:

- Before – 2009 to 2011
- After – 2013 to 2014

Table 4-7 – Crash summary for Site 3 – New England Highway, Harpers Hill

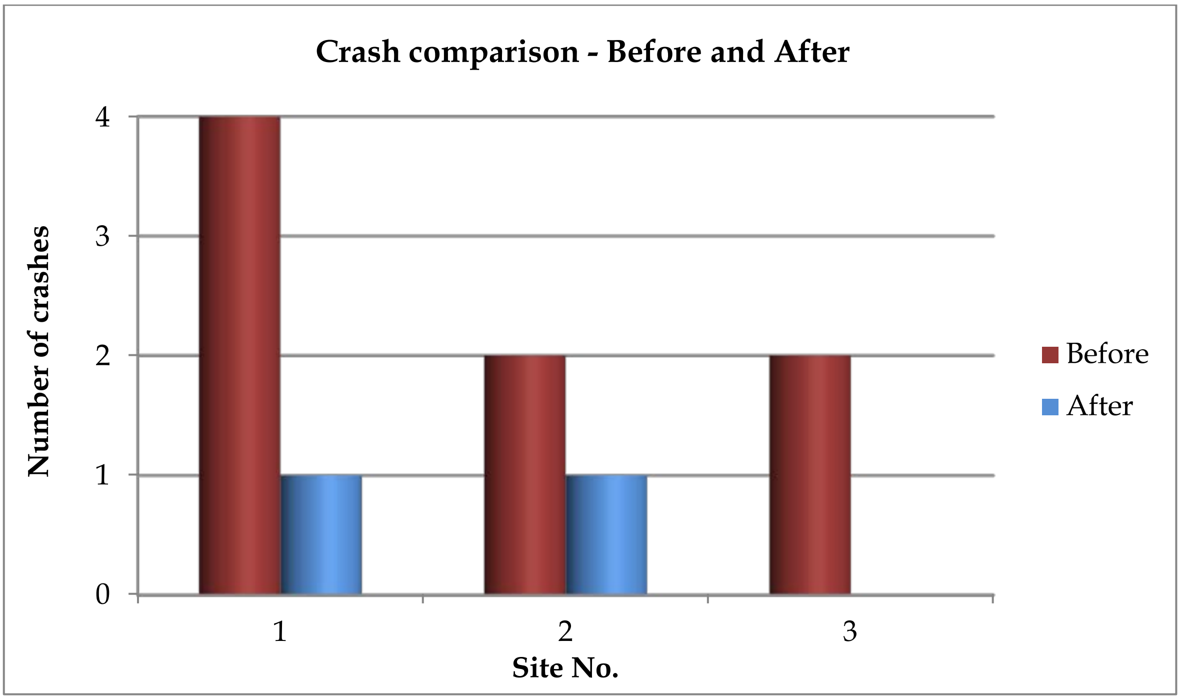
	Fatal	Injury	Non-Casualty	Total recorded crashes
Before	0	1	0	1
After	0	0	0	0

There is only one crash shown in Table 4-7. This crash was a rear end type crash resulting in injury and occurred before the zip merge treatment was implemented. The detailed crash report is included in appendix C.

4.3.4 Before and after crash summary

Results from the before and after crash comparison show that there have been a reduction in reported crashes since implementing the zip merge treatment. These results are shown below in Table 4-8.

Table 4-8 – Crash Comparison



The results shown in Table 4-8 do indicate a reduction in the occurrence of crashes at these locations. However, there are a number of factors that need to be considered when interpreting this result:

- The time period that the sites were analysed was quite short (2-3 years before/after). This is due to the fact that these zip merge treatments have been implemented quite recent. Crashes over a longer period (5-10 years) would provide a better indication of whether less crashes are happening because of the zip merge in place
- Also, the number of sites selected for crash comparisons is quite small. To provide conclusive evidence that adopting zip merges provide a reduction in crash rates, a lot more sites would need to be assessed. This study was unable to achieve due to the limited sites around the Hunter Region that are relevant

- There is also the point that crashes may not be occurring as a direct result of which merge treatment is in place. A number of factors, such as speed, alcohol, conditions, etc, need to be taken into considerations as well.

4.3.5 Cost benefit analysis

A cost benefit Analysis has been performed (Table 4-9) to determined the Cost Benefit Ratio (CBR) of implementing zip merge treatments. With RMS (2013) recommending using zip merge treatments in speed environments of 80km/h or less, the CBR only calculates the cost of implementing zip merges in 60, 70 and 80 km/h speed zones.

Table 4-9 – Cost benefit analysis

Item	Description	Crashes per year
Number of crashes at give-way merge	8 (over 9 years)	0.88
Number of crashes at zip merge	2 (over 5 years)	0.4
Reduction of crashes with zip merges		0.48
Cost to the community per crash	$ 110,000 (Table 2.5, average value for lane change and rear end for rural and urban)	
Items required to implement zip merge treatment (Average value between 60,70,80 km/h speeds)	Amount required	Cost ($)
Pavement overlay (m²)	470	250
Signposting (per sign)	2	1000
Edge linemarking + RRPM's (per/m)	115	10
	Total	$ 123,550
CBR - period 20 years (expected pavement life)		
	Reduction in crashes over 20 year period	9.6
	Cost to the community over the time period ($)	$ 1,056,000
	Cost of implementing the treatment ($)	$ 123,550
	CBR	**8.5**

From the CBR analysis in Table 4-9, it was found that a CBR of around 8.5 could be achieved with investment into zip merge treatments. As the cost of implementing the treatment is relatively low, it is expected that the CBR would increase with the increase in speed environments.

5. RESULTS AND DISCUSSION

5.1 Observed Driver Behaviours

The results from the site investigation analysed in Chapter 4 provide some good insight into the way in which zip merges are operating in NSW. There were mixed results in the way the observed zip merges were operating. The two sites (2 & 6) comprising of added lanes were implemented to increase capacity at the intersections, vehicles at these sites were found to be merging as soon as gaps appeared in the continuing through lane. This resulted in many drivers merging well before the merge taper, thus providing no real benefit to that of a give-way merge. Listed below is the key findings throughout the site observations.

- Point where drivers were observed merging
- How drivers were merging
- Brake usage during merging
- Blinker usage during merging

5.1.1 Point where drivers were observed merging

At the zip merge sites performing well (sites 1, 3 & 5) drivers were observed utilising the merge areas. Utilising the full length of the merge areas resulted in low merge angles between the through and merging vehicles, which:

- Adds safety by reducing the potential crash severity
- Allows the drivers more time to react to potential issues at the merge (e.g. adjacent vehicle not letting the car in by closing gaps)
- Allows adjacent vehicles more time to adjust to an appropriate speed

5.1.2 How drivers were merging

Throughout the study, it was noticed that drivers were displaying good behaviour towards other motorists whilst merging. This reinforces the findings from Styles and Luk (2006), where they found that zip merging had the potential to influence positive driver behaviour.

The fundamental purpose of zip-merging is to adopt this '1-for-1' style approach when merging. This was a really positive find, as it is known public knowledge that there has long been difficulties with give-way merges because of drivers exercising their right, and not willing to let vehicles in.

5.1.3 Brake usage during merging

Brake usage was observed to be quite low (average of 2.0%) at all merge sites. It was also witnessed that when brakes were used, it was not under heavy braking. More so, drivers were only tending to use their brakes to adjust their speeds in order to mate the vehicle's speed in the adjacent lane.

5.1.4 Blinker usage

Blinker usage observed was generally quite low (21%) in the zip merge sites performing well. The three sites where drivers were using blinkers more (73%), were the sites that vehicles were merging early. This shows that generally where a 'forced' merge is occurring, drivers are tending to indicate more often then in times where 'free' merging is occurring.

Perhaps another reason why blinker usage was low at zip merge sites is because motorists are gaining confidence with using them. This would indicate that drivers are becoming more aware of their presence and how they operate.

5.2 Safety

5.2.1 Merge taper lengths

The merge taper length is a critical element in a merge conflict, as it will decide on the time and rate the driver has to complete the merge. Through comparing merge taper lengths between Australia (Austroads) and the United States (AASHTO), it was found that the formulae used between the two agencies were different. In the United States, the formula took into account the posted speed as well as the width of the lane, where as in Australia the rate of lateral movement comfortable to the driver is also taken into account. The different merge taper formulae used results in a varying length of merge length and is shown below in Table 5-1.

Table 5-1 – Comparison of standards at lane reductions

Speed (km/h)	Length (m)	
	AUS (Austroads)	US (AASHTO)
50	81	56
60	97	81
70	113	110
80	130	174
90	146	196
100	162	217
110	178	239

The length of merge taper required in for lane drops (Table 5-1) show a considerable difference between Australia and America. At low speeds (< 80km/h) the length specified by Austroads is consistently larger than that of AASHTO, however once the design speed reaches 80 km/h (50 mph) or more, the merge taper length given in AASHTO is increasingly larger than that of Austroads. The length of merge taper given in AASHTO provides the driver with more time to merge in high-speed environments, providing added road safety in areas of roads where crash severity is high due to increased vehicle speeds.

During site observations, merge taper lengths were found to satisfy at least the minimum length specified by Austroads. Often (4 out of 6 sites) the merge taper lengths were above the minimum, which is desirable in un-constrained environments, adding to safety.

5.2.2 Signposting

As mentioned previously in the literature review (section 2.3.1), the number of crashes increases with the number of unexpected situations and decisions that need to be made by the driver. A road environment that incorporates consistent geometric features, signposting and delineation will assist in providing a familiar and expecting travel for motorists. As of today's signposting standards, there are different signage employed for the varying merge environments. Different signposting at lane reductions are shown below in Figure 5.1.

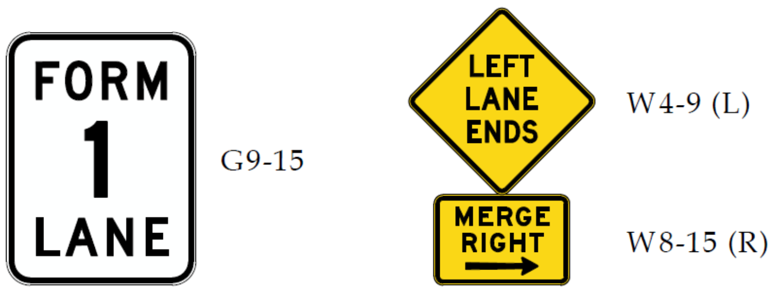


Figure 5.1 – Signposting at merge treatments (Standards Australia 2009)

Looking at differentiating signposting at merge treatments, there are a number of differences that could affect driver decisions. These differences include:

- G9-15 signs have larger dimensions that W4-9 and W8-15 signs. G9-15 signs include larger and less text also, making it easier for drivers to read and diverting their attention from the road for less time.
- Signposting numbers starting with G represent Guide signs, where as signposting numbers starting with W represent Warning signs. Drivers

The G9-15 sign is a more recent sign that is replacing the W4-9 and W8-15 as zip merges are more frequently introduced. The eventual phasing out of the traditional merge will hopefully result in less varied road signage, reducing confusion on roads due to signposting.

Through site visits, signposting was observed conforming to Australian standard 1742.2 at 5 out of the 6 zip merge sites. Toronto road (site 2), was one of the two zip merge sites that were performing below expectations. However, the signposting deficiencies at this site is not considered a major contributor to poor performance level.

5.2.3 Merge angles

The angle that vehicles merge at is of particular interest. If vehicles utilise the entire merge length given, the angle between the merging vehicle and the through lane is minimised. If there was a crash involving two vehicles (side by side) at a merge, lowering of the angle between vehicles travelling side by side would result in a lesser degree impact. This point is further emphasised with the aid of a diagram showing different merge angles (Figure 5.2).

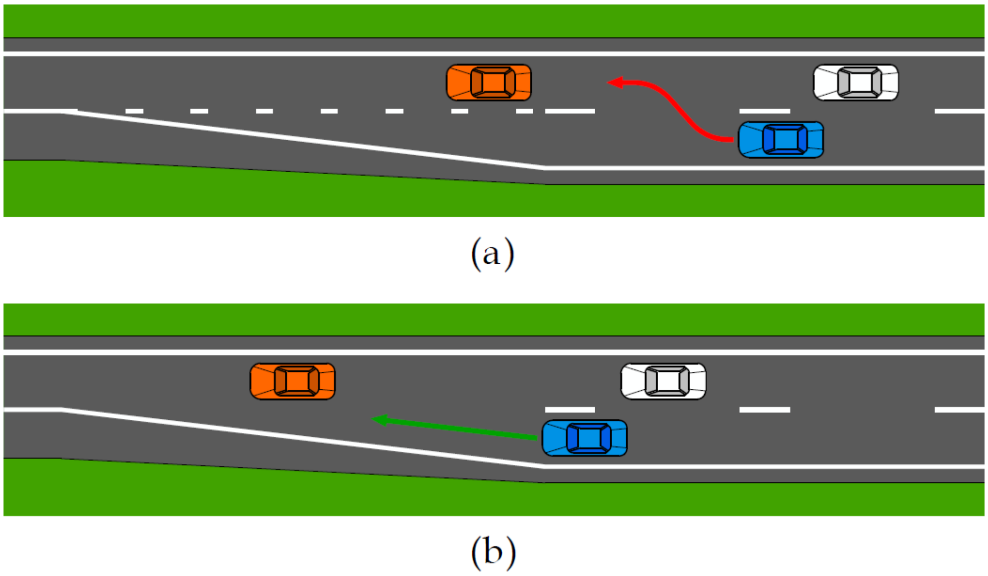


Figure 5.2 – Merge angles: (a) high angle, (b) low angle

Whilst observing driver behaviour at the zip merge sites, those that were performing well were utilising the full extent of merge lane, like that of Figure 5.2b). This correlates with the findings from Styles and Luk (2006), which they concluded that zip merging encouraged the fuller use of the merge lane.

All the merge locations were not employing this characteristic. Zip merge sites that were position directly after a set of traffic signals displayed a high percentage of motorists merging early, such as in Figure 5.2a. In this situation, vehicles tend to 'dive' into the lane at the first chance when a gap appears. This results in a higher angle between adjacent vehicles, resulting in a greater impact and potentially of a higher severity if a crash was to occur.

It should be noted however, although vehicles were merging before the merge taper at sites 2 and 6, there was no radical driving witnessed at these locations. Therefore, it is believed that although no real safety benefit is shown at these sites, there is no indication that these zip merges were performing any worse than they would if give-way merges were implemented.

5.2.4 Driver influence

Prendegast M, Kamper A and Reardon N (2013) Acknowledge that there is a need to increase awareness on road rules. They also explain that road user interactions highly indicate problems sharing the road because of this confusion amongst motorists.

In February 2013, the Centre for Road Safety launched the inaugural Road Rules Awareness Week. As part of road rules awareness week, the Centre for Road Safety developed NSW's first Top Ten Misunderstood Road Rules guide (Transport for NSW 2013b). Prendegast M, Kamper A and Reardon N (2013) explain that there was extensive media coverage throughout the week, including:

- 6 TV stories
- 29 print stories (Daily Telegraph, Sydney morning Herald)
- 56 Radio mentions
- An article also featured in NRMA's Open Road magazine

They also mention that there was community engagement, where the Centre for Road Safety had a team quiz more than 50 people on road rules in the Sydney CBD. Results of the quiz showed that an average of 71% were answered correctly (Prendegast M, Kamper A & Reardon N 2013). This result indicates that there is a lack of understanding on the road rules.

There is a clear indication that driver behaviours are influenced by their general understanding of the road rules. Therefore, it is essential that more is done to not only educate drivers better, but to target areas that impact directly on their behaviours, such as merging.

5.3 Efficiency

Studies have shown that utilisation of both lanes when approaching a merge in congested conditions can increase through put and reduce queue lengths (Mn/DOT 2004). Part of this research was to observe merge behaviours in congested conditions, and to make an analysis on lane utilisation during these conditions.

Cormorant Road (Site 1) experienced times of heavy congestion throughout the site observation. During times of congestion, it was noted that drivers in the merge lane were predominately staying in their lane right up until the point of merge. Drivers were also displaying quite good behaviour and adopting a one-for-one approach. An example of this is shown in Figure 5.3.

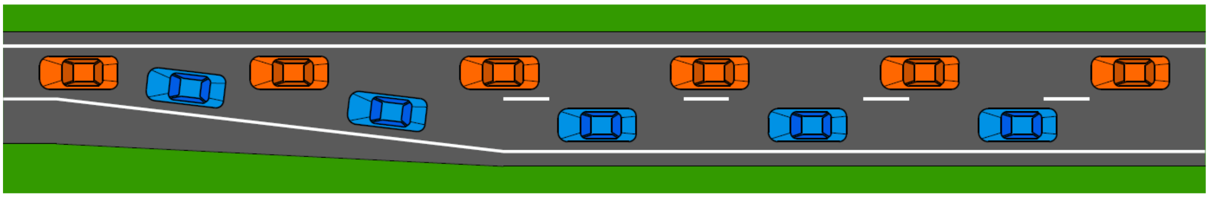


Figure 5.3 –Efficient merge practices found at zip merges

This behaviour was witnessed to be occurring at sites 1, 3 and 5, which shows that the zip merge system is working. The potential efficiency benefits become clear when compared to situations that can occur at give-way merges as a result of congested conditions. Scenarios where traffic starts to merge over early, resulting in an overwhelming split of traffic in the continuing lane. An example of this is shown in Figure 5.4.

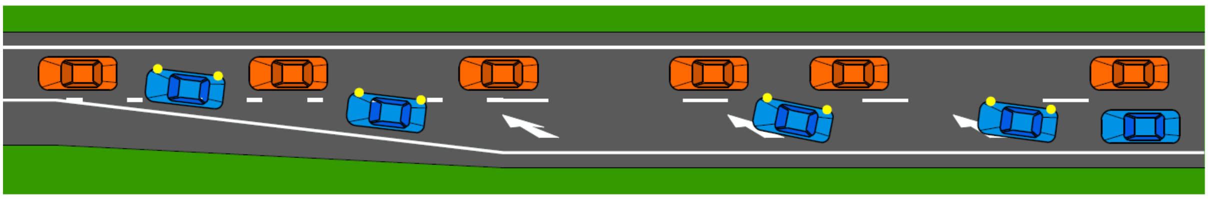


Figure 5.4 –Inefficiencies commonly found at give-way merges

In this example (Figure 5.4), the blue car in the middle is trying to merge early as a result of congested conditions up ahead. The orange car (second from the right) in response will try and close the gap, not allowing the blue car in (a common scenario when merging). This will open a gap between that and the orange car on the right, allowing the blue car second from the right to merge across. This can have a chain reaction, which eventually can turn into the situation that is seen below in Figure 5.5.

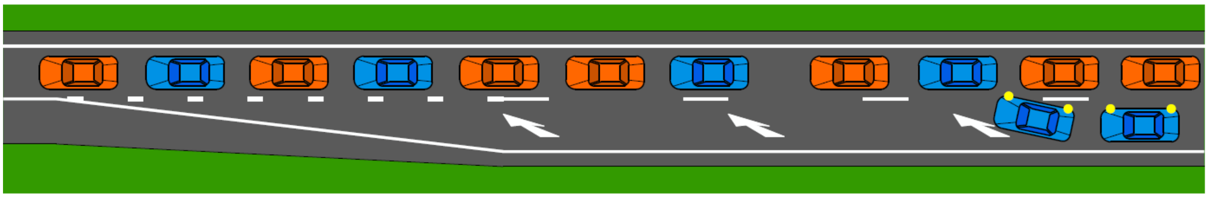


Figure 5.5 –Eventual bank up of traffic due to inefficient merging

The example situation in Figure 5.5 shows that merge lane eventually becomes obsolete, with a large queue of traffic building up in the continuing lane. This not only has through-put deficiencies, but can have safety implications with some cars continuing on in the merge lane with a high speed differential compared to the cars in the queue.

Mn/DOT (2004) has developed a late merge zipper system, which aims to keep vehicles in the merge lane, right up until the merge taper. Their studies have shown that this can have considerable benefits such as :

- Shorten queue lengths before work zone
- Increase traffic capacity
- Reduce aggressive driving
- Reduce travel times

The zipper system adopted by Mn/DOT (2004) employs the same principles as the zip merge system in Australia. If used correctly, there is potential for an increase in traffic capacity, and therefore efficiency.

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The following tasks were undertaken in order to provide some evidence of the likely ramifications with the introduction of zip merging and the phasing out of give way merges where lane drops occur:

- A review of local and overseas merge treatments and standards used in consultation with road authorities and a literature review
- On-site observations of zip merging behaviour in the Hunter region of NSW
- Investigation into crash data of a number of sites for a before and after comparison in an attempt to highlight possible safety benefits

6.1.1 Safety

Safety on our roads is of paramount importance. When a crash resulting in injury or death occurs, it can not only have a devastating effect on families and communities, but also cost the government huge amounts of money ($5.37 billion in NSW in 2011). Throughout this report, it was found that zip merging can provide a number of safety benefits, compared to that of traditional give-way merging. Safety benefits found include:

- Zip merging appears to encourage fuller use of the merge lane resulting in a reduction of merge angles, which could lead to a lower severity in crashes
- For general lane reductions, 96% of vehicles merged within the merge taper, with only 4% merging before the taper.
- Vehicles in adjacent lanes tend to adjust their speeds and position before the merge, minimising speed differences and allowing for a smooth merge
- Motorists were observed to be displaying good merging behaviour. Behaviour such as adopting a one-for-one approach and being courteous to other drivers, which is one of the problems found at traditional merge sites.
- Signposting standards adopted for zip merges are larger, clearer, and easier to read than signage for that traditional merges. Signage at zip merges tends to be aimed at engaging all road users (‘Form 1 lane’), instead of just the vehicle in the merge lane at traditional merges (‘Left lane ends merge right’).

The eventual phasing out of the traditional merge will hopefully result in less varied road signage, helping to reduce confusion. Programs such as the Road Rules Awareness Week are helping to increase knowledge of the roads and influence good driver behaviour, resulting in safer interaction of road users.

Although there is clear benefits to adopting zip merges, there is also a number of important issues to consider also:

- Whether potential benefits offset problems due to driver confusion during this transition period.
- Public support for zip merging may be lacking as it can be perceived as confusing. Therefore, investment into driver education on merging would be required.

6.1.2 Efficiency

During periods where traffic volumes are relatively low, a road users experience what is commonly referred to as 'free' merging. Nemeth and Rouphail (1983) have pointed out that traffic flow in merges only becomes interrupted when traffic flow exceeds a threshold value of about 1250 vph for a two lane merge. This situation results in there being insufficient gaps to allow the merge process to proceed. It is only when traffic volumes become quite high (above this threshold) that 'forced' merges occur and traffic queues start to appear. This is where identified characteristics of zip merges can provide efficiency benefits, such as

- A possible reduction in queue lengths as result of drivers tending to stay in their lanes right up until the merge taper
- Dynamic Zipper merge practices for highway construction zones adopt the same principles of zip merging. They have been found potentially increase throughput and reduce congestion, while reducing driver aggression

With increasing investment into driver education and awareness programs, promoting a better understanding of the zip merging system, hopefully problems with merging will end up a thing of the past.

6.2 Recommendations

With the phasing out of the traditional give-way merge, being replaced by zip merges, Potential problems of driver confusion could outweigh the potential benefits during this transition period. However, if there were more studies to prove the reliability of the data shown in this research, long term cost comparisons could favour the adoption of zip merges everywhere.

6.2.1 Implementing zip merges on Freeways

The severity of crashes rise in proportion to the speeds that vehicles are travelling. With merging being seen as a problem amongst motorists, the full extent of safety and efficiency implications would only fully be realised when dealing with merging onto roads in high speed environments, such as freeways and motorways.

There is a lot of freeways in NSW, along with hundreds, if not thousands of on-ramps, a lot of which require merging. Therefore, implementing zip-merging on freeways would be no small feat. However, to start with, there could be a number of sites that are showing a high crash rate or complaints. These sites could be converted and studied by:

- implement zip merges at a number of freeway on-ramps and study the interaction of vehicles and behaviour at both zip-merge and non-zip merge sites.
- Along-side implementation, invest in advertisement about the changes, as well as emphasising key considerations; being ‘courteous and ‘one-for-one’)

If the zip merge treatment was found to be producing good results, and this could prove to save money through accident costs, this could aid in an attempt to boost funding for the long term shift toward zip merging.

6.2.2 Alternative zip merge treatments

In a time of transition for the adopted merge treatments around Australia, there is the potential to further research and explore alternative zip merge treatments. The philosophy of the zip merge (one-for-one) would remain the same, however the merge taper could adjusted. For example in Figure 6.1, instead of the onus being on the vehicle in the nearside lane, the merge could taper in from both sides.

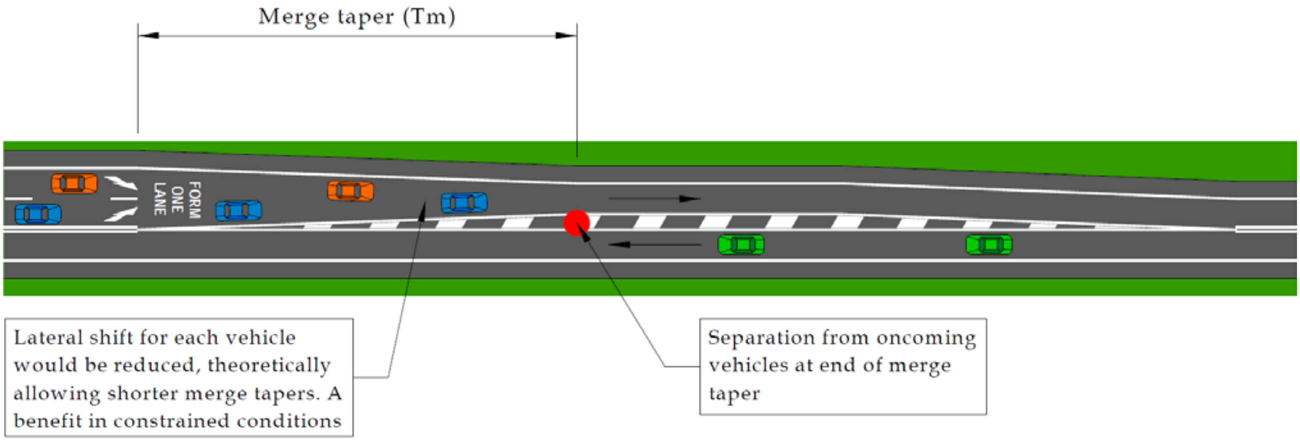


Figure 6.1 – Alternative zip merge treatment

The alternative merge treatment shown in Figure 6.1 shows a lateral shift for both lanes throughout the merge taper. This could potentially have a number of advantages, such as:

- Increased safety from oncoming motorists due to the separation of the opposing traffic streams at the end of the merge taper (shown as a red dot in Figure 6.1)
- Prompts driver alertness in both lanes
- Potentially reduce merge taper length as lateral shift would be halved. This would be quite beneficial in constrained environments

However, there would potentially be a number of disadvantages, which include:

- A higher cost of construction due to the wider pavement at the end of the merge taper
- A possible reduction in safety with two adjacent lanes having to shift laterally

6.2.3 Driver Education

Merging is well known for driver confusion, however merging is just one of the many areas that confusion exists. Other areas include roundabouts, School zones, U-turns and giving way. (Prendegast M, Kamper A and Reardon N (2013)) explained about initiatives from the Centre for Road Safety (Road Rules Awareness Week), as one of the measures to try and refresh drivers about the road rules. However, the simple fact is; after a person is granted their licence (as young as 20 years of age), they are under no obligation to take part in any further education, advising them of rule changes or common mistakes by drivers etc.

One such measure that could be put in place is to get licence holders to do a quick quiz each time they need to renew their drivers licence. This way they would already be in the motor registry facility getting their photo taken, so completing a short quiz (like that of your P2 Licence) while waiting for the licence to be printed would not be too taxing. The quiz could be aimed solely at areas where drivers have been identified of being commonly unaware. Aimed more as a refresher than a test, so that they can have as many goes as they like until they get the right answer.

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31. Transport for NSW 2013a, *Principles and Guidelines for Economic Appraisal of Transport Investment and Initiatives*

32. Transport for NSW 2013b, *Top 10 misunderstood road rules in NSW*, Roads and Maritime Services.

33. U.S. Department of Transportation 2009a, *Manual on Uniform Traffic Control Devices*, Part 2 Signs, Federal Highway Administration, Federal Register.

34. U.S. Department of Transportation 2009b, *Manual on Uniform Traffic Control Devices*, Part 3 Markings, Federal Highway Administration, Federal Register.

35. URS 2003, *Dynamic Late Merge System Evaluation*, Minnesota Department of Transportation.

36. Zhong, J & Chee, D 2009, *Road Safety Thematic Audit: High Speed Merging Facilities*, Parsons BrinckerHoff, Ernst & Young Centre, Level 27, 680 George Street, Sydney,<.

Appendix A Project Specification

University of Southern Queensland
Faculty of Engineering and Surveying

ENG 4111/2 Research Project
Project Specification

FOR: Chris Franks

TOPIC: SAFETY AND EFFICIENCY BENEFITS OF IMPLEMENTING ZIP MERGE TREATMENTS IN NSW

SUPERVISORS: Dr Soma Somasundaraswaran – University of Southern Queensland
Justin Drinkwater – Roads and Maritime Services

SPONSORSHIP: Roads and Maritime Services (RMS)

PROJECT AIM: Investigate Zip merge treatments and evaluate their effectiveness in different merge environments (high/low speed). Highlight the inconsistency of merge treatments used in NSW. Determine the safety aspects of this type of merge treatment and its appropriateness in different road environments.

TASK:

1. Research the background information (nationally & internationally) relating to the type of merge treatments and standards used under different road authorities.
2. Determine possible safety and efficiency benefits through analysing crash data and other relevant information.
3. Look at the possible data/scenarios to do 'Before and After study(s)' to evaluate the effectiveness of zip merge treatments.
4. Analyse available data to help identify key parameters contributing to road crashes at merges.

As time permits:

5. Create a community questionnaire with approval from RMS, which asks a number of questions relating to general understanding and thoughts on the alternative merge treatments. Evaluate the results from the community response.
6. Develop a strategy for the design and implementation of zipper merges for NSW roads, as currently no clear criteria for use exists.

AGREED:

Student: ____________________ (Chris Franks) Date: 15 / 10 /2014

Supervisor: ____________________ (Dr Soma Somasundaraswaran) Date: 28 / 10 /2014

Appendix B Excel Data

SITE 1: Cormorant Road, Kooragang		
Date	10/07/2014	
Start time	8:30am	
Finish time	9:30am	
Weather	Fine	
Total traffic count (vph)	1303	(%)
Volume in lane being reduced	630	48.3
Volume in continuing lane	673	51.7
Number of vehicles braking	18	1.4
Number of vehicles using blinker	102	16.2
Number of vehicles merging early	54	8.6
Number of vehicles merging inside	575	91.3
Number of Vehicles merging late	1	0.2
General Comments: *Majority of vehicles utilised the merge taper *Low blinker usage, perhaps motorists feel comfortable with a 1-4-1 treatment without the need of blinkers		

SITE 2: Toronto Road, Woodrising		
Date	4/09/2014	
Start time	3:30pm	
Finish time	4:30pm	
Weather	Fine, p/cloudy	
Total traffic count (vph)	1194	(%)
Volume in lane being reduced	274	22.9
Volume in continuing lane	920	77.1
Number of vehicles braking	37	3.1
Number of vehicles using blinker	165	60.2
Number of vehicles merging early	190	69.3
Number of vehicles merging inside	84	30.7
Number of Vehicles merging late	0	0.0
General Comments: * Constant early merging witnessed *Incorrect signposting "Left Lane Ends" "Merge Right" located after traffic signals		

SITE 3: New England Highway, Harpers Hill		
Date	9/10/2014	
Start time	8:30am	
Finish time	9:30am	
Weather	Overcast	
Total traffic count (vph)	670	(%)
Volume in lane being reduced	557	83.1
Volume in continuing lane	113	16.9
Number of vehicles braking	10	1.5
Number of vehicles using blinker	123	22.1
Number of vehicles merging early	11	2.0
Number of vehicles merging inside	546	98.0
Number of Vehicles merging late	0	0.0
General Comments: * Merge over crest, sight distance is below standard * Majority of vehicles tracked edge line through merge. Drops back to 60km/h shortly after merge.		

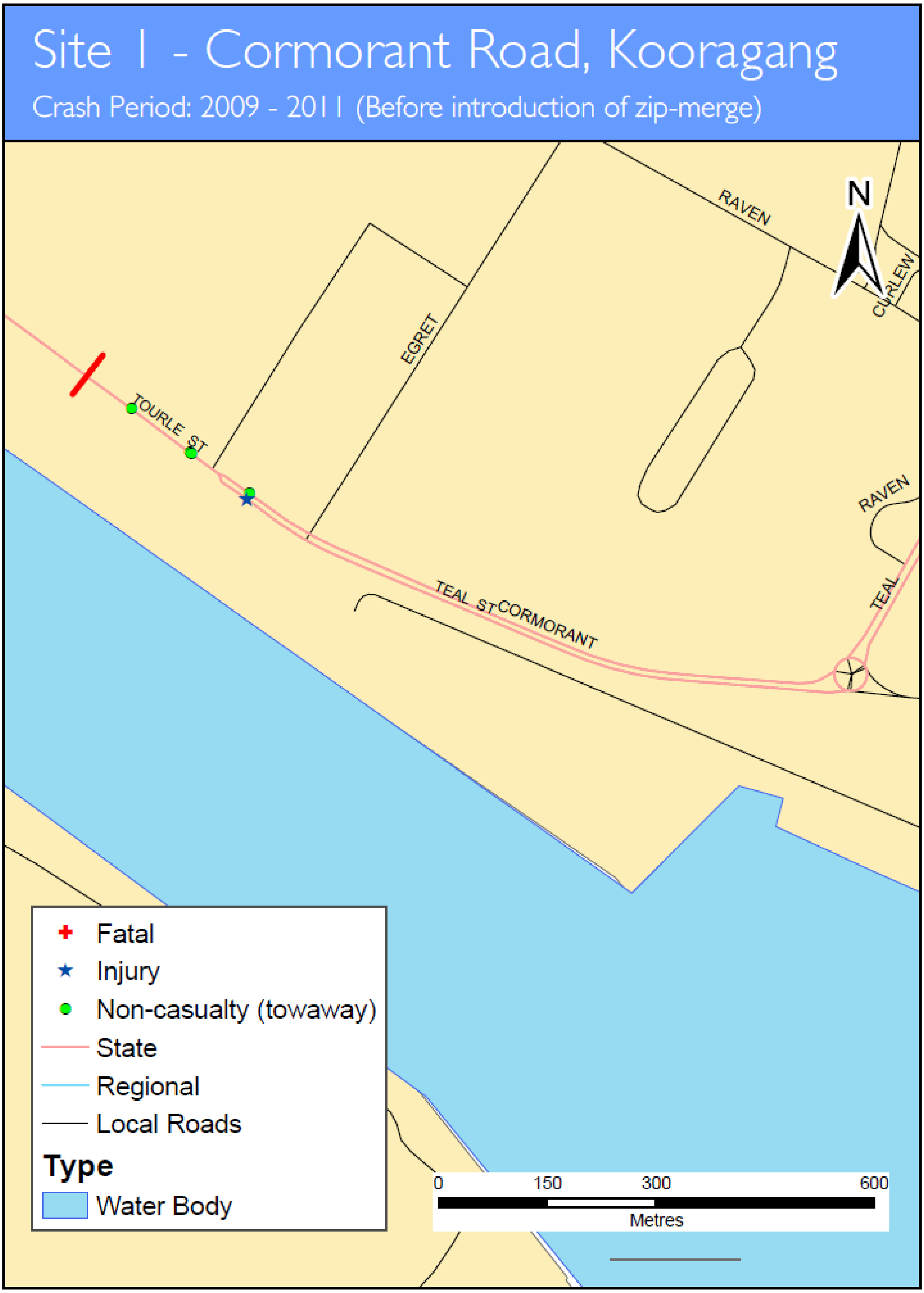
SITE 4: Hillsborough Road, Warners Bay		
Date	8/09/2014	
Start time	8:00am	
Finish time	9:00am	
Weather	Fine, sunny	
Total traffic count (vph)	1920	(%)
Volume in lane being reduced	330	17.2
Volume in continuing lane	1590	82.8
Number of vehicles braking	43	2.2
Number of vehicles using blinker	264	80.0
Number of vehicles merging early	235	71.2
Number of vehicles merging inside	93	5.8
Number of Vehicles merging late	2	0.1
General Comments: * Very high volume of traffic, few gaps * Vehicles were not utilising the acceleration length *Did utilise accel length & merge taper where larger gaps		

SITE 5: Weakleys Drive, Beresfield		
Date	11/09/2014	
Start time	8:00am	
Finish time	9:00am	
Weather	Fine, sunny	
Total traffic count (vph)	723	(%)
Volume in lane being reduced	240	33.2
Volume in continuing lane	483	66.8
Number of vehicles braking	16	2.2
Number of vehicles using blinker	56	23.3
Number of vehicles merging early	18	7.5
Number of vehicles merging inside	222	92.5
Number of Vehicles merging late	0	0.0
General Comments:		
* Blinkers were generally only used when congested * Brake usage was witnessed as drivers attempting to even the speeds of vehicles in adjacent lane		

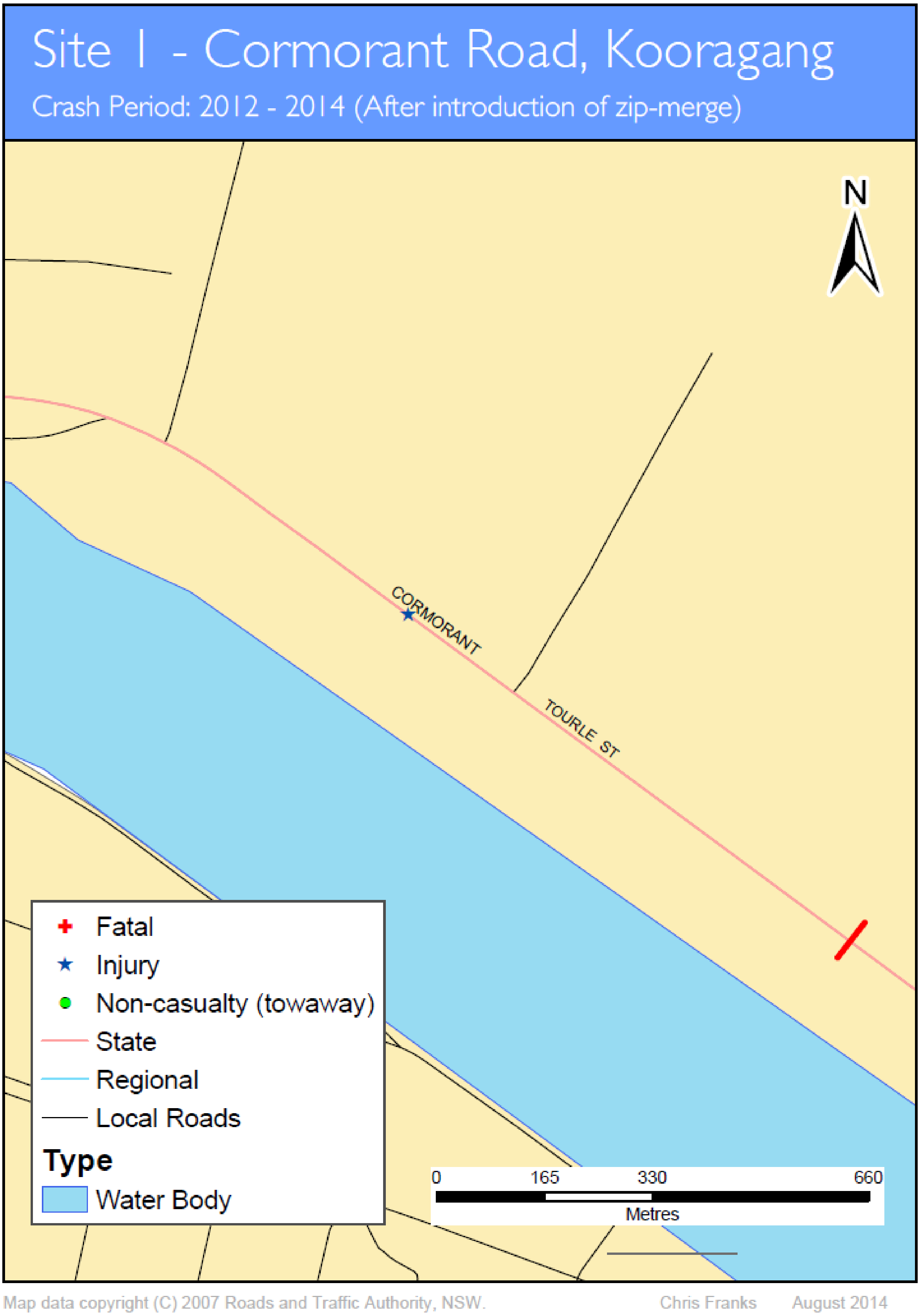
SITE 6: Newcastle Road, Cameron Park		
Date	20/09/2014	
Start time	8:30am	
Finish time	9:30am	
Weather	Overcast	
Total traffic count (vph)	2166	(%)
Volume in lane being reduced	425	19.6
Volume in continuing lane	1741	80.4
Number of vehicles braking	42	1.9
Number of vehicles using blinker	330	77.6
Number of vehicles merging early	248	58.4
Number of vehicles merging inside	176	41.4
Number of Vehicles merging late	1	0.2
General Comments:		
*Majority of vehicles were positioned in the two far-side lanes *Platoons of about 50 cars each time *Cars were merging as soon as gaps appeared		

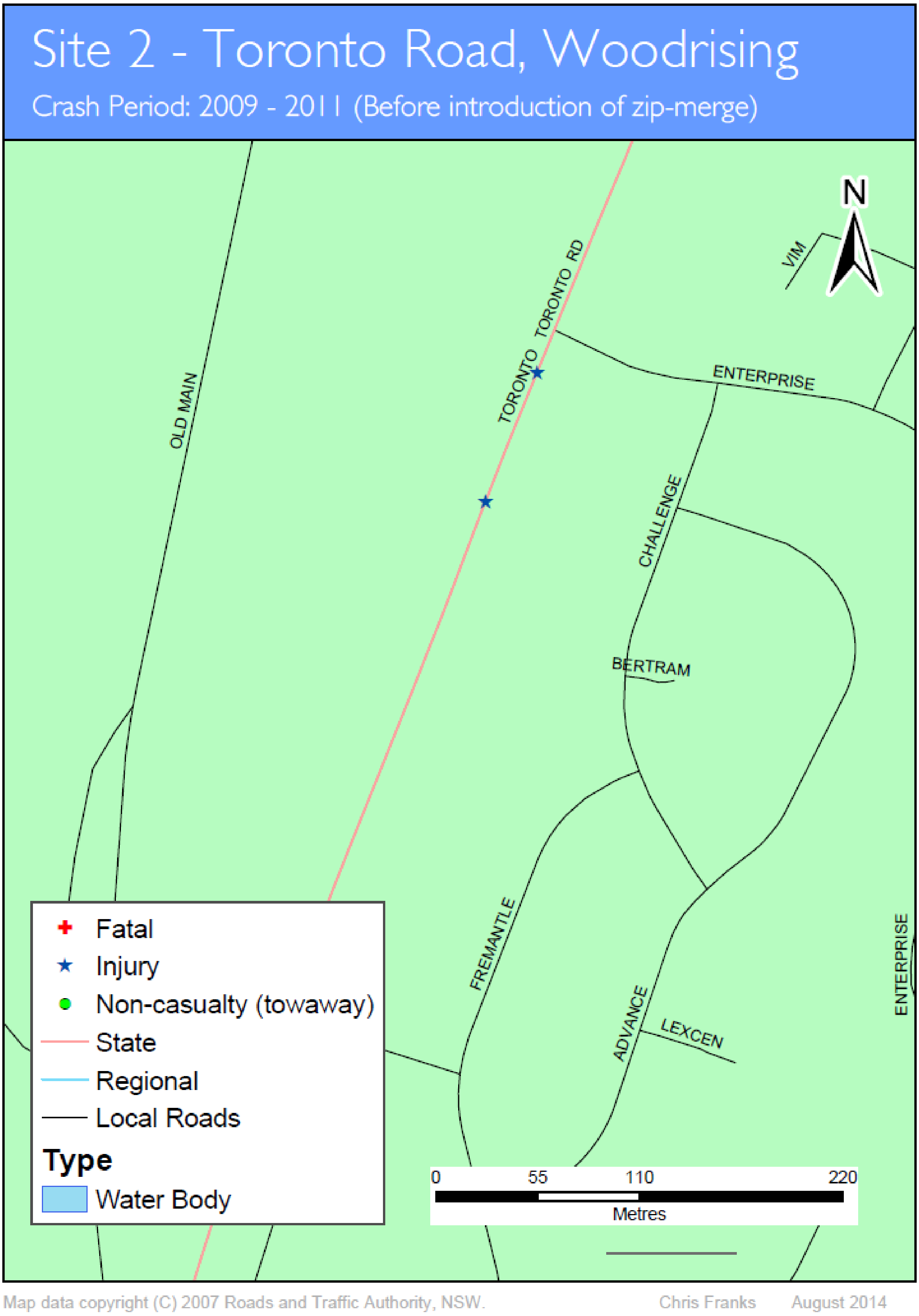
Site	Road	Location	Posted Speed	AADT	Date of AADT
1	Cormorant RD	Kooragang	80	15868	Oct-10
2	Toronto RD	Woodrising	80	14293	Feb-13
3	New England HWY	Harpers Hill	90	9588	Jun-13
4	Hillsborough RD	Warners Bay	60	12924	Nov-08
5	Weakleys Drive	Beresfield	60	9904	Mar-14
6	Newcastle RD	Cameron Park	90	15413	Mar-14

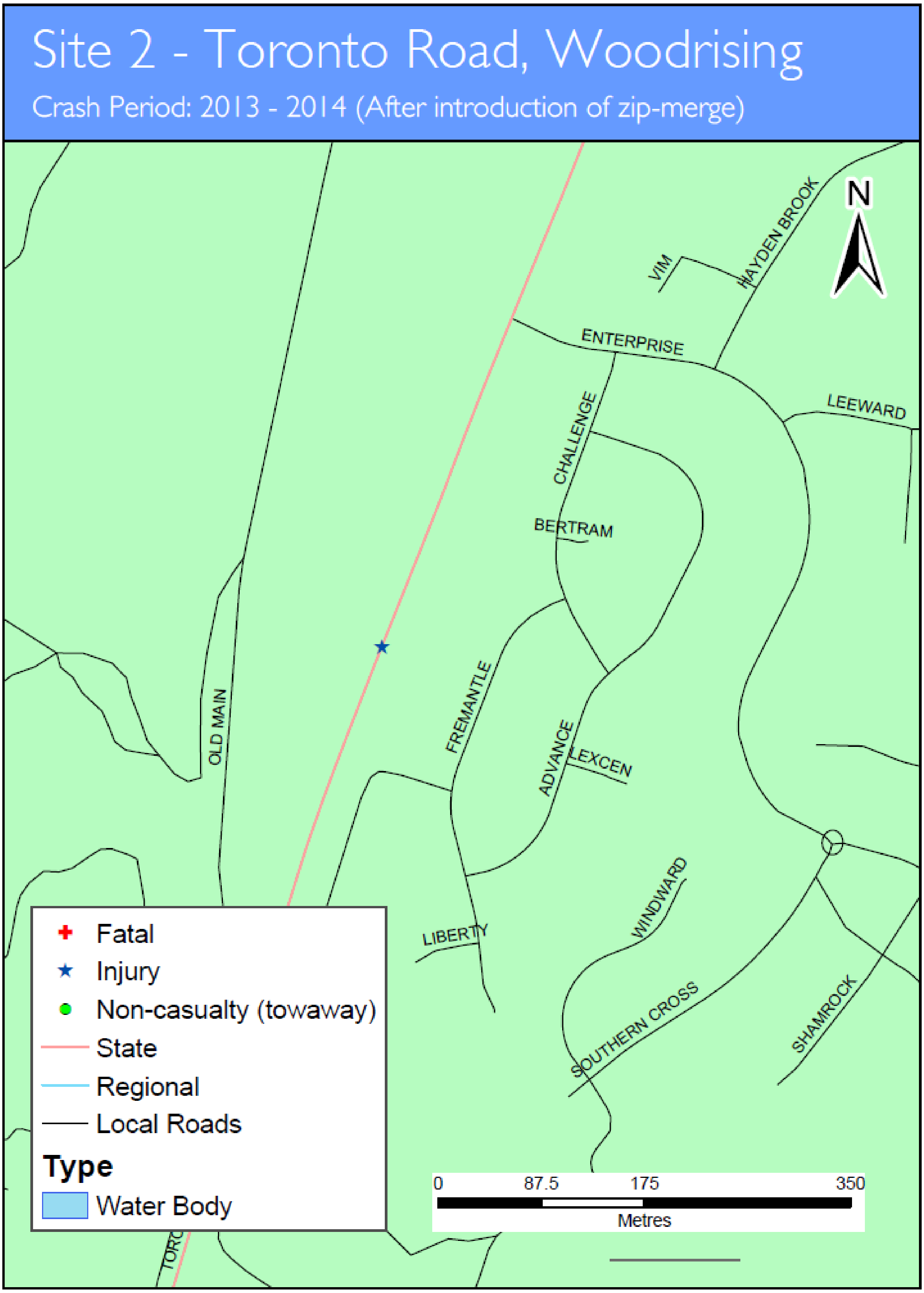
Appendix C CrashLink Data



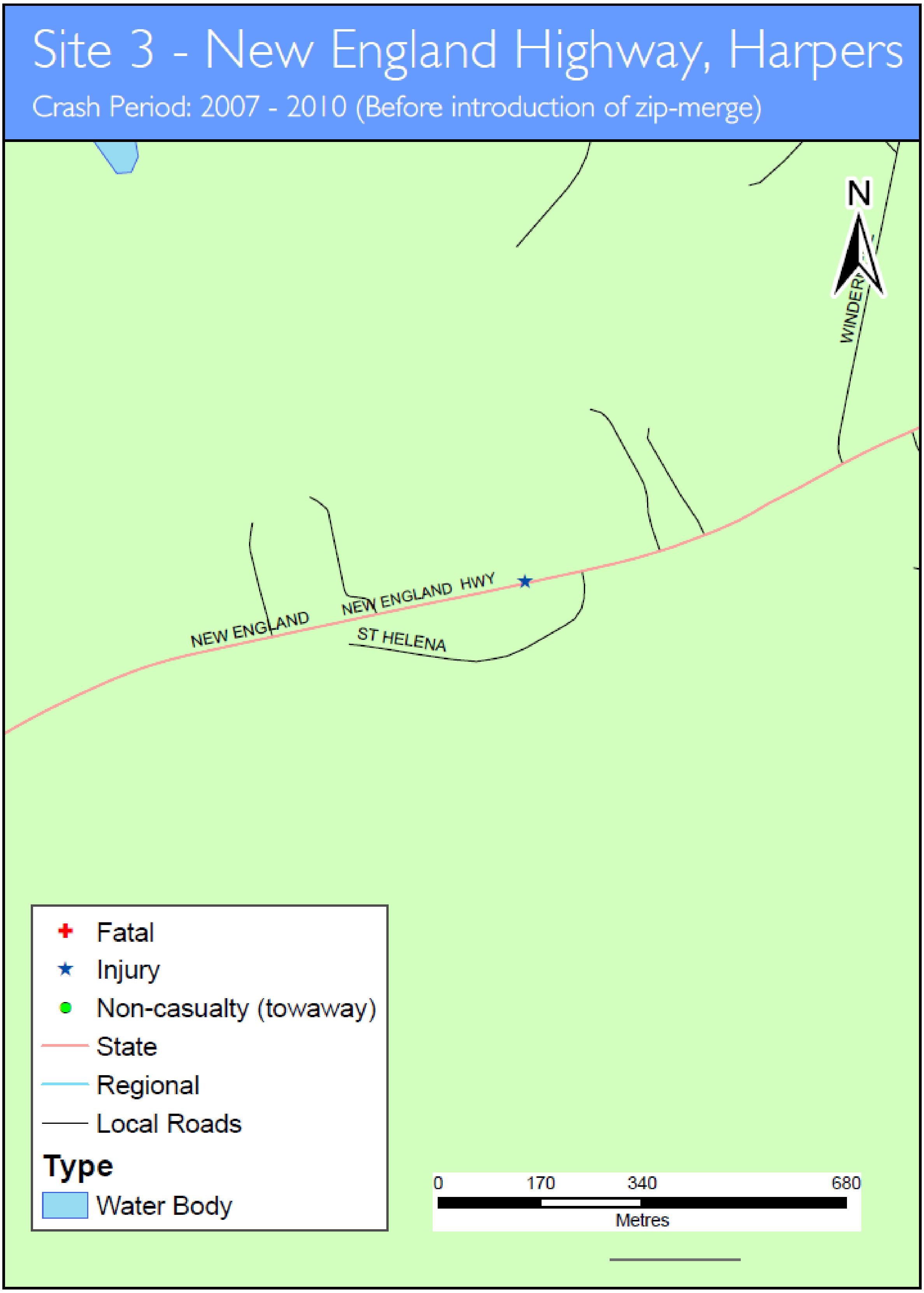
 Chris Franks August 2014


Site 1 - Cormorant Road, Kooragang
Crash Period: 2012 - 2014 (After introduction of zip-merge)
N
CORMORANT
TOURLE ST
Fatal
Injury
Non-casualty (towaway)
State
Regional
Local Roads
Type
Water Body
0
165
330
660
Metres
Map data copyright (C) 2007 Roads and Traffic Authority, NSW.
Chris Franks
August 2014

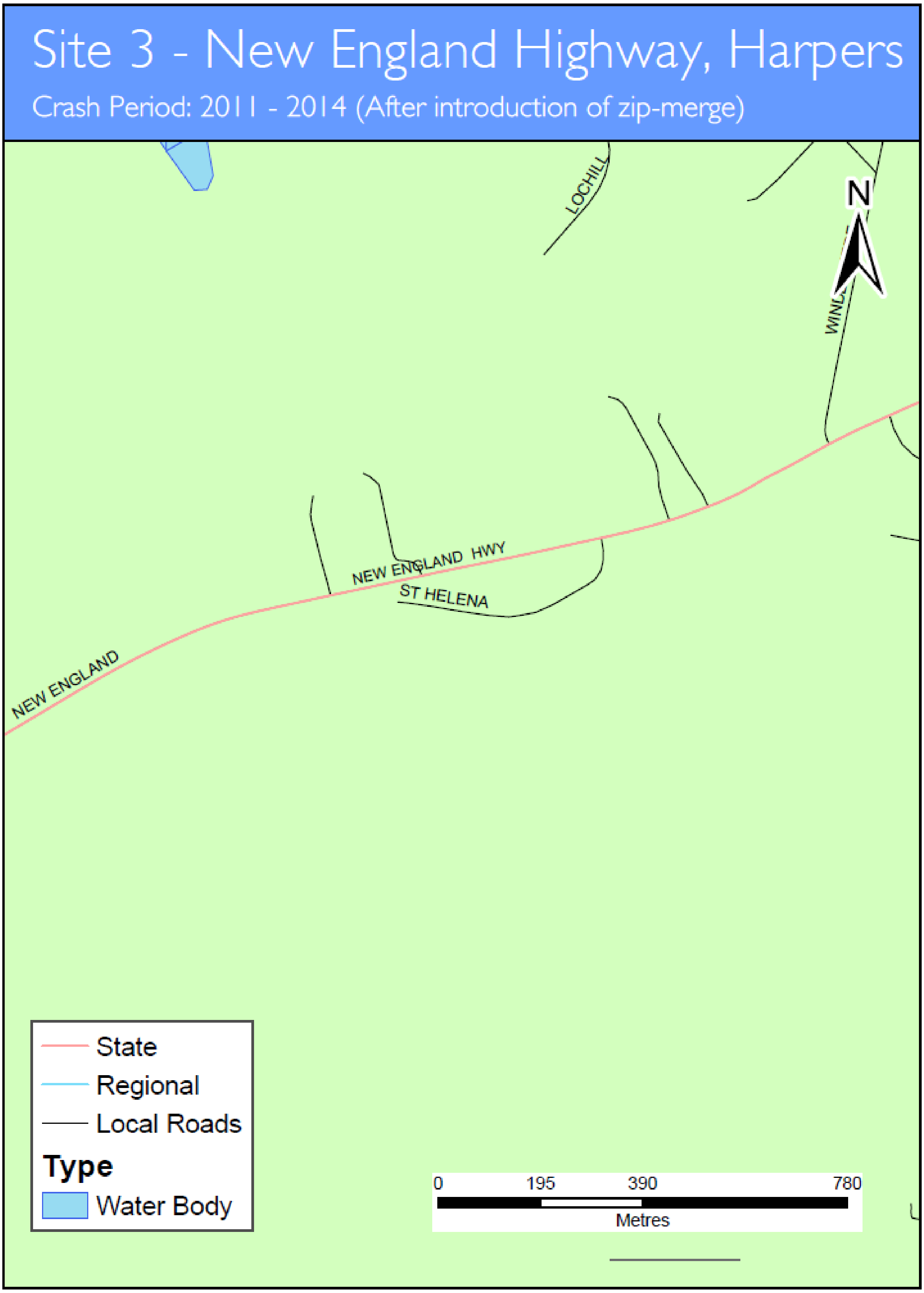

Site 2 - Toronto Road, Woodrising
Crash Period: 2009 - 2011 (Before introduction of zip-merge)
N
TORONTO RD
TORONTO
OLD MAIN
VIM
ENTERPRISE
CHALLENGE
BERTRAM
FREMANTLE
ADVANCE
LEXCEN
ENTERPRISE
Fatal
Injury
Non-casualty (towaway)
State
Regional
Local Roads
Type
Water Body
0
55
110
220
Metres
Map data copyright (C) 2007 Roads and Traffic Authority, NSW.
Chris Franks
August 2014



Map data copyright (C) 2007 Roads and Traffic Authority, NSW. Chris Franks August 2014



Map data copyright (C) 2007 Roads and Traffic Authority, NSW. Chris Franks August 2014



 Chris Franks August 2014

Site 1 - Cormorant Road

Detailed Crash Report

Crash No.	Date	Day of Week	Time	Distance	ID Feature	Loc Type	Alignment	Weather	Surface Condition	Speed Limit	No. of Tus	Tu Type/Obj	Age/Sex	Street Travelling	Speed Travelling	Manoeuvre	Degree of Crash	Killed	Injured	Factors
																				SF
Hunter Region																				
Newcastle LGA																				
Kooragang																				
Cormorant Rd																				
658392	08/03/2009	Sun	09:50	100 m W	EGRET ST	2WY	STR	Fine	Dry	80	1	P/C	M64	W in CORMORANT RD		Proceeding in lane	I	0	1	
E36424352						RUM:	74	On road-out of cont.												
668768	30/04/2009	Thu	17:00	100 m W	EGRET ST	DIV	STR	Overcast	Dry	80	2	CAR	F21	W in CORMORANT RD	65	Proceeding in lane	I	0	1	
E37922742						RUM:	30	Rear end				CAR	M43	W in CORMORANT RD	10	Proceeding in lane				
706927	21/04/2010	Wed	07:45	200 m W	EGRET ST	2WY	STR	Fine	Dry	80	3	TRK	M32	E in CORNORANT RD	60	Proceeding in lane	N	0	0	
E40926240						RUM:	30	Rear end				4WD	M26	E in CORNORANT RD	0	Stationary				
												TRK	M28	E in CORNORANT RD	0	Stationary				
714026	17/06/2010	Thu	11:50	200 m W	EGRET ST	2WY	STR	Raining	Wet	80	2	CAR	F30	W in CORMORANT RD	80	Proceeding in lane	N	0	0	
E41015875						RUM:	30	Rear end				4WD	F36	W in CORMORANT RD	0	Stationary				

Report Totals: Total Crashes: 4 Fatal Crashes: 0 Injury Crashes: 2 Killed: 0 Injured: 2

Crashid dataset Cormorant Road - Kooragang - Before

Detailed Crash Report

Crash No.	Date	Day of Week	Time	Distance	ID Feature	Loc Type	Alignment	Weather	Surface Condition	Speed Limit	No. of Tus	Tu Type/Obj	Age/Sex	Street Travelling	Speed Travelling	Manoeuvre	Degree of Crash	Killed	Injured	Factors
																				SF
Hunter Region																				
Newcastle LGA																				
Kooragang																				
Cormorant Rd																				
796758	08/05/2012	Tue	07:45	2 km W	TEAL ST	2WY	STR	Fine	Dry	80	2	LOR	M39	W in CORMORANT RD	50	Proceeding in lane	I	0	1	
E47963021						RUM:	30	Rear end				CAR	M20	W in CORMORANT RD	0	Stationary				

Report Totals: Total Crashes: 1 Fatal Crashes: 0 Injury Crashes: 1 Killed: 0 Injured: 1

Crashid dataset S1 - Cormorant - After

Site 2 - Toronto Road

Detailed Crash Report

Hunter Region
Lake Macquarie LGA
Woodrising
Toronto Rd

Crash No.	Date	Day of Week	Time	Distance	ID Feature	Loc Type	Alignment	Weather	Surface Condition	Speed Limit	No. of Tus	Tu Type/Obj	Age/Sex	Street Travelling	Speed Travelling	Manoeuvre	Degree of Crash	Killed	Injured	Factors SF
659979	26/02/2009	Thu	01:09	25 m	S ENTERPRISE WAY	2WY	STR	Fine	Dry	80	2	CCH	M56	N in TORONTO RD	80	Proceeding in lane	I	0	1	
E36786768						RUM:	4	Ped walk with				PED	M25	N in TORONTO RD		Walk with traffic				
655521	06/02/2009	Fri	16:00	100 m	S ENTERPRISE WAY	2WY	STR	Fine	Dry	70	2	CAR	M U	N in TORONTO RD	10	Perform U-turn	I	0	1	
E36252023						RUM:	40	U turn				CAR	M44	N in TORONTO RD	70	Proceeding in lane				

Report Totals: Total Crashes: 2 Fatal Crashes: 0 Injury Crashes: 2 Killed: 0 Injured: 2

Crashid dataset S1 - Toronto - Before

Detailed Crash Report

Hunter Region
Lake Macquarie LGA
Woodrising
Toronto Rd

Crash No.	Date	Day of Week	Time	Distance	ID Feature	Loc Type	Alignment	Weather	Surface Condition	Speed Limit	No. of Tus	Tu Type/Obj	Age/Sex	Street Travelling	Speed Travelling	Manoeuvre	Degree of Crash	Killed	Injured	Factors SF
853826	30/09/2013	Mon	17:45	300 m	S ENTERPRISE WAY	2WY	STR	Fine	Dry	80	3	CAR	M24	S in TORONTO RD	50	Proceeding in lane	I	0	2	
E53353563						RUM:	30	Rear end				CAR	F50	S in TORONTO RD	0	Stationary				
												CAR	F29	S in TORONTO RD	0	Stationary				

Report Totals: Total Crashes: 1 Fatal Crashes: 0 Injury Crashes: 1 Killed: 0 Injured: 2

Crashid dataset S1 - Toronto - After

Site 3 - New England Highway

Detailed Crash Report

Crash No.	Date	Day of Week	Time	Distance	ID Feature	Loc Type	Alignment	Weather	Surface Condition	Speed Limit	No. of Tus	Tu Type/Obj	Age/Sex	Street Travelling	Speed Travelling	Manoeuvre	Degree of Crash	Killed	Injured	Factors S F
Hunter Region																				
Maitland LGA																				
Lochinvar																				
New England Hwy																				
560399	05/03/2007	Mon	18:00	100 m W	ST HELENA CL	2WY	STR	Fine	Dry	60	2	TRK	M28	E in NEW ENGLAND HWY	75	Proceeding in lane	I	0	1	S
E104277596						RUM:	30	Rear end				WAG	M49	E in NEW ENGLAND HWY	Unk	Proceeding in lane				

Report Totals: Total Crashes: 1 Fatal Crashes: 0 Injury Crashes: 1 Killed: 0 Injured: 1

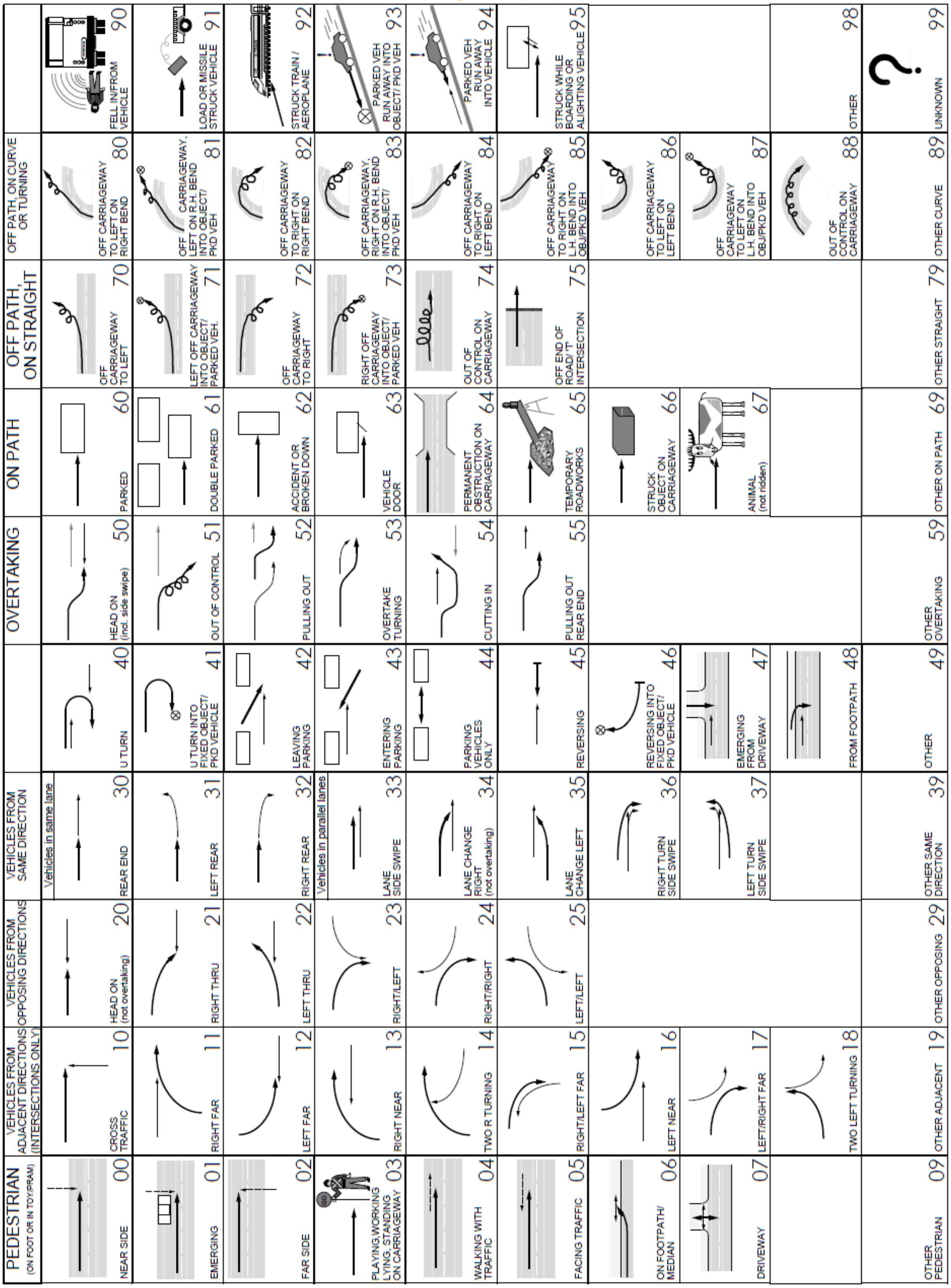
Crashid dataset New England Highway - Harpers Hill - Before

Detailed Crash Report

Crash No.	Date	Day of Week	Time	Distance	ID Feature	Loc Type	Alignment	Weather	Surface Condition	Speed Limit	No. of Tus	Tu Type/Obj	Age/Sex	Street Travelling	Speed Travelling	Manoeuvre	Degree of Crash	Killed	Injured	Factors S F
Hunter Region																				
Maitland LGA																				
Lochinvar																				
New England Hwy																				
786733	26/01/2012	Thu	09:00	200 m W	ST HELENA CL	2WY	STR	Raining	Wet	60	1	CAR	M51	W in NEW ENGLAND HWY	100	Veering left	I	0	1	S
E403820091						RUM:	70	Off road to left												

Report Totals: Total Crashes: 1 Fatal Crashes: 0 Injury Crashes: 1 Killed: 0 Injured: 1

Crashid dataset New England Highway - Harpers Hill - After

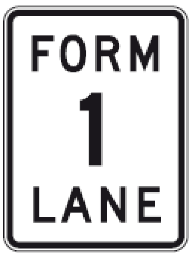

PEDESTRIAN (ON FOOT OR IN TOY/PRAM)
NEAR SIDE 00
EMERGING 01
FAR SIDE 02
PLAYING,WORKING LYING, STANDING ON CARRIAGEWAY 03
WALKING WITH TRAFFIC 04
FACING TRAFFIC 05
ON FOOTPATH/ MEDIAN 06
DRIVEWAY 07
OTHER PEDESTRIAN 09
VEHICLES FROM ADJACENT DIRECTIONS (INTERSECTIONS ONLY)
CROSS TRAFFIC 10
RIGHT FAR 11
LEFT FAR 12
RIGHT NEAR 13
TWO R TURNING 14
RIGHT/LEFT FAR 15
LEFT NEAR 16
LEFT/RIGHT FAR 17
TWO LEFT TURNING 18
OTHER ADJACENT 19
VEHICLES FROM OPPOSING DIRECTIONS
HEAD ON (not overtaking) 20
RIGHT THRU 21
LEFT THRU 22
RIGHT/LEFT 23
RIGHT/RIGHT 24
LEFT/LEFT 25
OTHER OPPOSING 29
VEHICLES FROM SAME DIRECTION
Vehicles in same lane
REAR END 30
LEFT REAR 31
RIGHT REAR 32
Vehicles in parallel lanes
LANE SIDE SWIPE 33
LANE CHANGE RIGHT (not overtaking) 34
LANE CHANGE LEFT 35
RIGHT TURN SIDE SWIPE 36
LEFT TURN SIDE SWIPE 37
OTHER SAME DIRECTION 39
U TURN 40
U TURN INTO FIXED OBJECT/ PKD VEHICLE 41
LEAVING PARKING 42
ENTERING PARKING 43
PARKING VEHICLES ONLY 44
REVERSING 45
REVERSING INTO FIXED OBJECT/ PKD VEHICLE 46
EMERGING FROM DRIVEWAY 47
FROM FOOTPATH 48
OTHER 49
OVERTAKING
HEAD ON (incl. side swipe) 50
OUT OF CONTROL 51
PULLING OUT 52
OVERTAKE TURNING 53
CUTTING IN 54
PULLING OUT REAR END 55
OTHER OVERTAKING 59
ON PATH
PARKED 60
DOUBLE PARKED 61
ACCIDENT OR BROKEN DOWN 62
VEHICLE DOOR 63
PERMANENT OBSTRUCTION ON CARRIAGEWAY 64
TEMPORARY ROADWORKS 65
STRUCK OBJECT ON CARRIAGEWAY 66
ANIMAL (not ridden) 67
OTHER ON PATH 69
OFF PATH, ON STRAIGHT
OFF CARRIAGEWAY TO LEFT 70
LEFT OFF CARRIAGEWAY INTO OBJECT/ PARKED VEH. 71
OFF CARRIAGEWAY TO RIGHT 72
RIGHT OFF CARRIAGEWAY INTO OBJECT/ PARKED VEH 73
OUT OF CONTROL ON CARRIAGEWAY 74
OFF END OF ROAD/ 'T' INTERSECTION 75
OTHER STRAIGHT 79
OFF PATH, ON CURVE OR TURNING
OFF CARRIAGEWAY TO LEFT ON RIGHT BEND 80
OFF CARRIAGEWAY. LEFT ON R.H. BEND INTO OBJECT/ PKD VEH 81
OFF CARRIAGEWAY TO RIGHT ON RIGHT BEND 82
OFF CARRIAGEWAY, RIGHT ON R.H. BEND INTO OBJECT/ PKD VEH 83
OFF CARRIAGEWAY TO RIGHT ON LEFT BEND 84
OFF CARRIAGEWAY TO RIGHT ON L.H. BEND INTO OBJ/PKD VEH 85
OFF CARRIAGEWAY TO LEFT ON LEFT BEND 86
OFF CARRIAGEWAY TO LEFT ON L.H. BEND INTO OBJ/PKD VEH 87
OUT OF CONTROL ON CARRIAGEWAY 88
OTHER CURVE 89
FELL IN/FROM VEHICLE 90
LOAD OR MISSILE STRUCK VEHICLE 91
STRUCK TRAIN / AEROPLANE 92
PARKED VEH RUN AWAY INTO OBJECT/ PKD VEH 93
PARKED VEH RUN AWAY INTO VEHICLE 94
STRUCK WHILE BOARDING OR ALIGHTING VEHICLE 95
OTHER 98
UNKNOWN 99

Appendix D Excerpts from Standards Australia

Signpost class definition

Class	Function
Regulatory signs (Type R)	To regulate the movement of traffic by indicating when or where a legal requirement applies, failure to comply with which constitutes an offence.
Warning signs (Type W)	To warn road users of unexpected or hazardous conditions on or adjacent to the road.
Direction signs (Type G)	To inform and advise road users of directions, destinations, route names and distances, non-regulatory traffic instructions, the location of tourist and service facilities for road users, and points of interest.
Expressway direction signs (Type GE)	To inform and advise road users on expressway type roads of directions, destinations, route distances, non-regulatory traffic instructions, the location of services for travellers and other points of interest.
Temporary signs (Type T)	To control, warn and guide road users safely through, around or past work sites on roads and footpaths and to warn and advise of other temporary hazardous conditions that could endanger road users.
Hazard markers (Type D)	To delineate a marked change in the direction of travel or to emphasize the presence of an obstruction.

Sign sizes

Sign	Name	Sign No.	Size mm	Principal references*
	LEFT LANE ENDS	W4-9B	750 × 750	AS 1742.2
		W4-9C	900 × 900	
	MERGE RIGHT	W8-15A	Not used	AS 1742.2
		W8-15B	750 × 500	
		W8-15C	900 × 600	
	FORM 1 LANE	G9-15A	600 × 800	AS 1742.2
		G9-15B	900 × 1200	
		G9-15C	1200 × 1600	