Austroads

Research Report
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Infrastructure Improvements to Reduce Motorcycle Casualties

Infrastructure Improvements to Reduce Motorcycle Casualties

Prepared by

David Milling, Dr Joseph Affum, Lydia Chong and Samantha Taylor

Project Manager

Melvin Eveleigh

Abstract

This report presents the technical findings of a two-year study which sought to identify effective infrastructure improvements to reduce motorcycle crash risk and crash severity, based on how riders perceive, respond and react to infrastructure they encounter.

The project commenced with a literature review of national and international guides, publications and research papers, which also enabled the identification of knowledge gaps and areas where further detail was required. A crash analysis was undertaken to demonstrate the relationship between motorcycle crashes, travel period, vehicle configuration (i.e. motorcycle only and multiple vehicle crashes involving a motorcycle), road geometry, road layout (e.g. intersection type) and crash types. For comparative purposes, vehicle crashes at the same location were also analysed.

Explanations of why, and how, road infrastructure elements influence motorcycle crash risk were researched and are provided within this report. This primarily involved identifying how the design and condition of road infrastructure elements can influence either the likelihood of a crash occurring or the resulting severity of a crash. Where a number of elements that would increase the likelihood or severity of a crash were present concurrently, the proportionate increase in risk was demonstrated using the AusRAP model.

The study has built up a compendium of treatments, presented in such a way that engineering decisions to manage these elements can be justified, even if outside of existing design warrants, and asset management and maintenance practice.

The research highlights that motorcycles should be identified as an individual road user group and considered as a 'design vehicle' during road design and asset management and maintenance practices.

It is concluded that motorcycle crash risk can be managed, but requires changes in practice, in design, asset management funding and routine maintenance performance contracts. One example is in the identification of road sections and/or routes that pose the highest crash risk to motorcyclists, so that they can be managed and maintained appropriately. In addition, the author advocates proactive motorcycle specific network safety assessments and road safety audits, as well as fine-tuning in design parameters for roads carrying significant volumes of motorcyclists (e.g. horizontal geometry, sight lines, lane and shoulder width, intersection types, intersection quality and controls). It is also suggested that the range and detail of mitigation measures be expanded.

Keywords

Motorcycle, motorcycle crash, motorcycle crash prevention, motorcycle infrastructure, motorcycle treatments, motorcycle safety, road safety

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Austroads Ltd.
Level 9, 287 Elizabeth Street
Sydney NSW 2000 Australia
Phone: +61 2 8265 3300
austroads@austroads.com.au
www.austroads.com.au

About Austroads

Austroads is the peak organisation of Australasian road transport and traffic agencies.

Austroads' purpose is to support our member organisations to deliver an improved Australasian road transport network. To succeed in this task, we undertake leading-edge road and transport research which underpins our input to policy development and published guidance on the design, construction and management of the road network and its associated infrastructure.

Austroads provides a collective approach that delivers value for money, encourages shared knowledge and drives consistency for road users.

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- Roads and Maritime Services New South Wales
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- Department of State Growth Tasmania
- Department of Transport Northern Territory
- Transport Canberra and City Services Directorate, Australian Capital Territory
- Australian Government Department of Infrastructure and Regional
- Australian Local Government Association
- New Zealand Transport Agency.

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Summary

Motorcycle crashes are a significant contributor to deaths and serious injury on our roads. As outlined in the Australian Transport Council's National Road Safety Strategy, in Australia, motorcycle riders made up 16% of all fatalities in 2012, and 22% of serious injury casualties despite representing only a very small percentage of total traffic volume (one per cent of vehicle kilometres travelled (VKT)). The rate of motorcyclist deaths per registered motorcycles is five times higher than the rate of occupant deaths per registered 4-wheeled vehicles. In recent years a clear upward trend in motorcycle crashes was identified in Australia and New Zealand.

This report highlights the relationship between motorcycle crashes and road infrastructure, and specifically, how road infrastructure influences both the likelihood of a crash occurring or the resulting severity of a crash.

The investigation included: a comprehensive literature review, crash analysis, the identification of road infrastructure elements as crash factors, the identification of effective mitigation measures and their likely safety benefit and consultations with stakeholders.

The objectives of the project were to:

- determine the influence of road infrastructure elements in motorcycle-related crashes, and
- identify countermeasures that have the potential to reduce the incidence and/or severity of such crashes.

Road infrastructure elements considered included design parameters (e.g. horizontal alignment, superelevation), road surface condition (including skid resistance), roadside hazards and overall maintenance condition.

The project is focused on providing guidance to practitioners, including a number of recommended updates to the Austroads Guides to Road Design, Traffic Management, Road Safety and Asset Management, some of these updates can be drawn directly from this report and some will need to be further researched before being changed within the Guides. It is also hoped that the project will contribute to several of the objectives within the Australian National Road Safety Strategy 2011-2020, including safety improvements on popular motorcycle routes (a specific action for the first three years of the strategy) and providing advice ahead of plans to introduce motorcycle black spot/black length programs in all jurisdictions (a 'future' action).

A literature review of national and international guides, publications and research papers demonstrated that guidance of road infrastructure elements that adversely affect motorcycle crash risk is available, however this is not comprehensive enough for a practitioner to make engineering decisions considering risk, cost and benefit.

A crash analysis was undertaken to demonstrate the relationship between motorcycle crashes, travel purpose period, vehicle configuration (i.e. motorcycle only and multiple vehicle crashes involving a motorcycle), road geometry, road layout (e.g. intersection type) and crash types. For comparative purposes, vehicle crashes at the same location were also analysed. This demonstrated that motorcycle crashes are effected by travel purpose period, with a majority of motorcycle crashes occurring during the week.

Explanations of why, and how, road infrastructure elements influence motorcycle crash risk were researched and are provided. This primarily involved identifying how the design and condition of road infrastructure elements can influence either the likelihood of a crash occurring or the resulting severity of a crash. Where a number of elements that would increase the likelihood or severity of a crash were present concurrently, the proportionate increase in risk was demonstrated using the AusRAP model.

The report has built up a compendium of treatments, presented and explained in such a way that engineering decisions to manage these elements can be justified, even if outside of existing design warrants, and asset management and maintenance practice.

The report highlights that motorcycles should be identified as an individual road user group and considered as a ‘design vehicle’ during road design and asset management and maintenance practices.

It is concluded that motorcycle crash risk can be managed, remedial treatments have been shown to be affective, however changes in practice are required in road design, asset management funding and routine maintenance performance contracts to proactively manage motorcycle crash risk. One example is in the specific identification of road sections and/or routes that pose the highest crash risk to motorcyclists, so that they can be managed and maintained appropriately. In addition, the author advocates proactive motorcycle specific network safety assessments and road safety audits, as well as fine tuning in design parameters for roads carrying significant volumes of motorcyclists (e.g. horizontal geometry, sight lines, lane and shoulder width, intersection types, intersection quality and controls). It is also encouraged that the range and detail of mitigation measures be expanded.

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1. Introduction

1.1 Background

Motorcyclists are the fastest growing sector of road users globally and represent an increasing proportion of road crash casualties in Australia and around the world (Rogers 2008, World Health Organisation n.d.). Motorcycle crashes are a significant contributor to deaths and serious injury on our roads. Australian motorcycle registrations increased by 61% between 2005 and 2011, and the number of injured motorcyclists increased by 14% during that same time period (Henley & Harrison 2008, Australian Bureau of Statistics 2010, Australian Bureau of Statistics 2012). In Australia, motorcycle riders made up 16% of all fatalities in 2012, and 22% of serious injury casualties despite representing only a very small percentage of total traffic volume (1% of VKT). The Australian National Road Safety Strategy (Australian Transport Council 2011) has identified a clear upward trend in motorcycle crashes in recent years, and the situation is similar in New Zealand.

1.2 Objective

The objective of this Austroads project is to determine the influence of road infrastructure elements on motorcycle-related crashes, and to identify countermeasures that have the potential to reduce the incidence and/or severity of such crashes.

Road infrastructure has an influence on motorcycle safety, particularly through issues such as road design elements (e.g. horizontal alignment, superelevation), road surface friction, roadside hazards and maintenance condition. This report focuses on road infrastructure treatments, as a result it primarily focuses on the safer roads pillar within the safe system pillars. However it is recognised that road infrastructure may cross over into the safe speeds and safe people pillars as some elements of road infrastructure can prompt motorcyclists to adjust their riding behaviour.

The outcomes from this research would be used to provide guidance to practitioners, including potential updates to the Guides to Road Design, Traffic Management, Road Safety and Asset Management. The project may also assist in meeting several of the objectives from the Australian National Road Safety Strategy 2011–2020, including safety improvements on popular motorcycle routes (an action for the first three years) and providing advice ahead of plans to introduce motorcycle black spot/black length programs in all jurisdictions (a 'future' action).

1.3 Method

The investigation methodology was as follows:

- Task 1 – literature review and internet search to identify if similar studies have been undertaken domestically and internationally to review any publications related to motorcycle crashes or treatments or strategies implemented by other road agencies
- Task 2 – compare passenger vehicle and motorcycle in Australia and New Zealand crashes by travel purpose (commuting and recreational) and by road feature (midblock – straight/curve, intersection type)
- Task 3 – identify road infrastructure as a factor in motorcycle crashes using publications from Australia and New Zealand as well as findings from motorcycle specific road safety audits
- Task 4 – identify mitigation measures based on the findings of Task 3 and discuss and confirm with stakeholders

- Task 5 – undertake stakeholder consultation with the Australian Motorcycle Council, state motorcycle advocacy groups, international road assessment program (iRAP), practitioners from road design, road safety, finance, road operations, network programs, asset management and maintenance road engineering disciplines of state and territory road agencies across Australia and New Zealand
- Task 6 – review Austroads Guides was undertaken to identify if technical guidance was provided for motorcycles and if that guidance would reduce motorcycle crash risk. Recommendations were made to update a guide where required
- Task 7 – undertake safety benefit analysis using the treatments outlined in the mitigation measures using an AusRAP assessment on an existing road with known motorcycle crash history. The safety benefit analysis is intended to demonstrate the motorcycle crash risk reduction and safety benefits that can be gained from investing in maintenance to maintain a high standard of road surface, delineation and signage. The analysis also is intended to show the safety benefit of using existing infrastructure design attributes and design parameters to reduce motorcycle crash risk.

1.4 Approved Safety Barrier Products

Safety barrier products referenced in this publication are included as examples of treatments used in different road environments and countries. Contact your local road agency for products approved for use in your jurisdiction.

2. Literature Review

2.1 Introduction

The literature review explores the current understanding of motorcycle crashes (single vehicle crash (motorcycle only) and multiple vehicle accidents (motorcycle and another vehicle)); the contributory factors; followed by a review of engineering treatments undertaken to address the risks and hazards posed to motorcyclists. Examination of Australian and international statistics, and research studies was undertaken to determine those contributory factors relating to the road infrastructure.

2.2 Crash Contributory Factors

This section identifies contributory factors, such as road design elements, roadside hazards and environmental conditions in single and multi-vehicle motorcycle crashes. Although human factors (factors relating to the behaviour or actions of motorcyclists or other road users) were identified in a high proportion of motorcycle crashes, the scope of this project means that they will only be discussed briefly for their relevance to infrastructure and road design.

2.2.1 Characteristics of Motorcycle Crashes

Analyses of motorcycle crash statistics were collated from government publications, research papers and other resources in Australia and overseas between 2005 and 2012.

The European experience is captured in the 2-Be-Safe project, *D2 Road infrastructure and road safety for PTW* (powered two wheelers) featuring analyses and studies to determine what road surface characteristics, condition, alignment parameters and installation influence motorcycle crash rates (2-Be-Safe 2010).

The crashes were characterised by the following:

- jurisdiction
- time of day and days of the week
- rural or urban roads[1]
- intersection or midblock
- posted speed limit
- single or multi-vehicle crashes
- severity, i.e. fatal, seriously injured, injured, property damage only, etc.

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[1] **NSW, Vic., WA, SA and NT:**
Urban road environment is defined as mainly built-up with all divided roads < 100 km/h. All roads where speed limit < 80 km/h and for NSW and SA intersections, where speed limit < 80 km/h.
Rural road environment is defined as mainly built-up and undivided roads where speed limit ≥ 80 km/h, mainly built-up and divided roads where speed limit ≥ 100 km/h for Vic. provincial cities, non-MSD cities/towns and small towns; for NSW country urban areas. Mainly open and all roads where speed limit ≥ 80 km/h. For NSW and SA intersections: mainly built-up and all intersections where speed limit > 80 km/h. For NSW and SA intersections: mainly open and all intersections where speed limit ≥ 80 km/h.
Qld and Tas.:
Urban road environment: all roads where speed limit < 80 km/h.
Rural road environment: mainly built-up and roads where speed limit 80–100 km/h or mainly open and all roads where speed limit ≥ 80 km/h.
ACT:
All roads are considered 'mainly built-up'. No fields to indicate level of urbanisation, divided/undivided or speed limit.
NZ:
Urban road environment: all roads where speed limit < 80 km/h are urban (U) roads.
Rural road environment: all roads where speed limit ≥ 80 km/h are open (O) roads.

Contributory factors identified include:

- human factors:
  - motorcyclist characteristics such as age, gender and experience
  - excessive speed
  - impairments – alcohol, drugs
  - skill of the motorcyclist in response to a situation encountered, e.g. swerving for obstacles and braking
- vehicle factors:
  - motorcycle engine capacity
  - roadworthiness, e.g. condition of the brakes
- environmental factors:
  - road design, e.g. sight distances, road geometry
  - roadside hazards
  - pavement conditions
  - wet or icy roads.

The majority of Australian statistics, in conjunction with more recent studies, cited in this review are from the Department of Infrastructure, Transport, Regional Development and Local Government (2008) report titled *Fatal and Serious Road Crashes Involving Motorcycles*.

This report classifies crashes as follows:

- for single vehicle motorcycle crashes:
  - run off carriageway (straight, right or left bend)
  - collision
  - overtaking
- for multiple vehicle crashes involving a motorcycle/s:
  - head-on collision in opposing directions
  - straight vs right turn in opposing directions
  - straight vs right turn at right angles
  - rear end in the same direction
  - other in the same direction
  - overtaking.

Motorcycle crashes vs motorcycle registration

The 2012 Road Deaths Australia report (Department of Infrastructure and Transport 2013), identifies that the rate of motorcyclist fatalities was 5.5 times higher than that of vehicle occupants. Vehicle occupant fatalities were 0.55 per 10 000 registered motor vehicles, compared with 3.16 per 10 000 motorcycles.

Australian motorcycle registrations increased by 61% between 2005 and 2011, and the number of injured motorcyclists increased by 14% during that same time period (Henley & Harrison 2008, Australian Bureau of Statistics 2010, Australian Bureau of Statistics 2012). Nationally, motorcycle riders make up 22% of serious casualties, yet motorcycles account for just 4.2% of all registered vehicles (Australian Bureau of Statistics 2013, Pointer 2013).

Influence of time, day, month of year and weather conditions

A study by Bambach et al. (2012) of over 1323 fatalities in Australia between 2001 and 2006 found that motorcycle crashes were fairly evenly distributed throughout the year, with slightly fewer occurring in the months of June to September.

The same study reported that around 57% of the fatalities occurred between noon and 8 pm. In New Zealand, Khoo and Stevens (2011) reported that crashes resulting in fatality or serious injury occurred mainly in dark conditions.

The majority of literature reviewed also stated that weather was not a primary cause for most motorcycle crashes as they often occurred on dry, fine days (Anderson et al. 2012, Bambach et al. 2012, Grzebieta et al. 2010,). Roughly 66% of the known cases occurred in fine and dry conditions and on dry road surfaces (Bambach et al. 2012).

Grzebieta et al. (2010) found that 54% of fatalities occurred on weekends and that 'riding as a recreational activity is generally known to be a predictor of crashes'.

Locations and road types

The Department of Infrastructure, Transport, Regional Development and Local Government (2008) found that 44% of multiple vehicle crashes involving motorcycle fatalities occurred on major arterial roads (including highways) and were more prevalent in urban areas.

The report also found that 28% of single vehicle crashes involving motorcycle fatalities occurred on major arterial roads (including highways) but were more prevalent in rural areas.

Allen et al. (2013) corroborated the statistics and revealed that the most common crash scenario in Victoria reported by motorcyclists was another vehicle turning into the path of the motorcyclist, with 68% of the cases occurring in urban areas.

Bambach et al. (2012) reported that fatalities were evenly distributed between arterial roads (26%), rural/private roads (26%), freeways or highways (25%) and suburban roads (21%), while Grzebieta (2010) reported that 70% of crashes occurred on arterial roads. This could be due to the difference in how studies classify the roads as the latter defined an arterial road as having posted speed limits from 60–100 km/h.

In Europe, 2-Be-Safe reported that powered two wheeler crashes (a category which encompasses both motorcycles and mopeds) overwhelmingly occurred in urban areas (up to 72%), with the highest severity found on rural roads, or 'roads outside built-up areas' (2-Be-Safe 2010). The UK study in the 2-Be-Safe project reported that motorbike incidents occurred more frequently on either A class or unclassified roads, with a single carriageway and a 30 mph speed limit. In Italy and the UK, the highest number of motorcycle incidents occurred on two-way single carriageway roads.

In EU countries, lateral collisions in Greece were reported to occur more frequently on carriageways with at least one lane in each direction while in Spain, run-off-road accidents accounted for half of motorcycle crashes on carriageways wider than seven metres but lacking hard shoulders.

Single and multi-vehicle crash types

Single vehicle accidents

The Department of Infrastructure, Transport, Regional Development and Local Government (2008) reported that in fatal single motorcycle crashes:

- 34% were off carriageway – right bend
- 23% were off-carriageway – left bend
- 22% were off-carriageway – straight
- 6% were hit an object
- 4% were loss of control while overtaking.

Analysis of the motorcycle crashes recorded in the Great Britain road accident database, STATS19, found that (2-Be-Safe 2010):

- 5.8% hit objects within the carriageway (mostly hit kerb, 2.7% and parked vehicles, 1.3%)
- 7.2% hit objects off the carriageway, a breakdown of the type of roadside objects hit is provided in Section 2.2.2.

Multiple vehicle accidents

According to the Department of Infrastructure, Transport, Regional Development and Local Government (2008) the proportion of multiple vehicle fatal crashes involving a motorcyclist fatality are as follows:

- 28% – head-on collisions for vehicles travelling in opposite directions
- 23% – 'straight vs right turn' in opposing directions
- 7% – 'straight vs right turn' crash for vehicles at right angles
- 6% – 'straight vs straight' collisions for vehicles at right angles
- 3% – rear end collisions
- 25% – 'other' collisions, although detail about this category was not given in the report.

In Greece, Spain and the UK, side impact crash types were the most common (2-Be-Safe 2010):

- In Greece, lateral collisions (side impact) in urban areas were most often observed on straight roads. In areas outside urban environments, narrow formations are exclusively related to lateral collisions. The proportion of the collision type lateral collision (side impact) by road type is as follows:
  - 68% of crashes in urban areas
  - 47% of crashes in rural areas.
- In Spain, collision type 'front to side' was common and rear-end and run-off-road collisions were more frequent outside of urban areas. The collision type 'front to side' as a percentage of all collisions by road type is as follows:
  - 38% of collisions in urban areas
  - 27% of collisions on express roads
  - 8% of collisions for motorways.
- The UK road accident database, STATS19, reported that:
  - 56.7% – the highest proportion of crashes occurred for the 'going ahead other' manoeuvre
  - 8.3% – 'overtaking moving vehicle on its offside'
  - 6.2% – 'going ahead left hand bend'.

About 21% of these motorcycle crashes involved skidding, and 3.5% skidding and overturning. In the majority of the crashes (73%) the motorcycle remained upright and this was associated with lower severity.

Engine capacity

Bambach et al. (2012) report that for Australia, the distribution of known crashes among different engine capacities are 42% for engines with less than 500 cc, 36% between 500 and 1000 cc, 22% for capacities greater than 1000 cc. However, since the paper did not compare the crash proportions with exposure on the percentage of each category that was registered, any inferences made regarding the relationship between engine sizes, crash rates or crash severities may be inaccurate.

NZ Transport Agency (NZTA) (2012) found that 'a higher proportion of crashes involving large motorcycles (500 cc or larger) resulted in death rather than injury' (i.e. 41% of the casualties but 60% of the deaths). The report speculates that this may be due to the inability of the motorcyclist to control the more powerful vehicle, or lack of experience and training.

A more powerful vehicle generally results in heavier mass and is able to accelerate quickly to higher speeds, resulting in less time to make safe decisions and increasing the likelihood a minor motorcycle handling error will result in loss of control.

Human factors

Human factors play a key role in most motorcycle crashes. When examining the contribution of human behaviour in a motorcycle crash, the following questions need to be considered:

- Were drugs or alcohol involved?
- In a multi-vehicle crash, could the key vehicle be identified (i.e. was the motorcyclist or the other vehicle responsible for the crash, or both)?
- Did the crash occur as a result of the motorcyclist taking actions to avoid a situation caused by another vehicle/motorcycle?
- Did the driver perceive the motorcyclist before colliding with them?
- Did the crash occur as a result of the motorcyclist taking actions to avoid obstacles on the road?
- Was the motorcyclist/vehicle driver travelling at speeds excessive for the conditions?
- Was the motorcyclist unable to respond in time to changing road conditions (e.g. patch of gravel on the road)?
- Was the motorcyclist unable to properly predict or respond in time to changing road geometry (e.g. reverse curves)?

Of all the possible factors involved, excessive speed is most commonly identified as the causal factor.

There is also mention in NZTA (2012) of how the road infrastructure, design, signage and delineation contribute to the decision-making of motorcyclists, such as in assessing curvature and grades, thus allowing the motorcyclist to adjust speed and motorcycle paths to negotiate curves. Discussion on road infrastructure is covered in Section 2.2.2, Contributory crash factors relating to road infrastructure and design.

Excessive speed, alcohol and drugs

As mentioned in the previous section, human factors make up a large proportion of the contributory factors in motorcycle crashes. The Department of Infrastructure, Transport, Regional Development and Local Government (DITRDLG) (2008) found that alcohol/drugs, excessive speed or speeds not suitable to the road conditions were contributory factors in the majority of crashes in Australia.

DITRDLG (2008) found that between 1999 and 2003 the main factors contributing to crashes involving the death of a motorcyclist were excessive speed (76%) and alcohol and/or drugs (46%) as shown in Table 2.1 and Table 2.2 for single vehicle and multiple vehicle crashes where the motorcyclist was at fault, respectively.

Note that there may be more than one factor attributed to each crash, e.g. alcohol, fatigue, speed and road infrastructure could all be factors in a crash. In instances where speed, alcohol, or a rider being a learner where identified as being the primary factor it is unlikely that road infrastructure could not have played a role in modifying riding behaviour or providing an inherent amount of safety (clear sightlines to oncoming alignments, safe roadsides) or opportunity for a rider to safely recover (surface grip, sealed shoulders for recovery).

Table 2.1: Main factors implicated in single vehicle crashes involving the death of a motorcyclist (1999–2003)

Factor	Count	% of known
Excessive speed	232	70
Alcohol and / or drugs	152	46
Learner rider	27	8
Skylarking or racing	8	2
Hit animal	15	5
Road infrastructure	6	2
No factor recorded	67	–

Source: Department of Infrastructure, Transport, Regional Development and Local Government (2008).

Table 2.2: Main factors allocated to the motorcycle in multiple vehicle crashes involving the death of a motorcyclist (1999–2003)

Factor	Count	% of known
Excessive speed	175	41
Alcohol and or drugs	91	21
Not see other road user	23	5
No factor recorded for crash	67	–

Source: Department of Infrastructure, Transport, Regional Development and Local Government (2008).

Table 2.3 shows the main factors for multiple vehicle motorcycle fatality crashes where the other vehicle was at fault. Did not see the other vehicle and fail to give way were the major factors reported in this case.

Table 2.3: Main factors allocated to the other vehicle in multiple vehicle crashes involving the death of a motorcyclist (1999–2003)

Factor	Count	% of known
Not seeing other road user	85	19
Fail to give way	31	7
Alcohol and/or drugs	10	3
Excessive speed	6	2
No factor recorded for crash	71	–

Source: Department of Infrastructure, Transport, Regional Development and Local Government (2008).

Grzebieta et al. (2010) confirmed the findings for Australia and New Zealand between 2001 and 2006, that 74% of the fatalities with known causes involved speed, alcohol, drugs, or a combination of all three. In New South Wales, ‘excessive speed’ was recorded for 48% of single vehicle crashes, although due to the definition, the vehicles may not necessarily be speeding when compared to the posted speed limit, but were travelling too fast for the conditions.

Khoo and Stevens (2011) also stated that drug, alcohol and speed each contribute towards ‘higher risk’ in more severe injury motorcycle crashes.

At-fault vehicle

According to the Motorcycle Council of NSW (2013), in a multi-vehicle motorcycle collision, the distribution of at-fault vehicle (vehicle most likely to be responsible for the crash) is:

- the other driver – 38%
- the motorcyclist – 22%.

In a multi-vehicle collision, as a percentage of recorded crashes, when the other driver was at fault the collision occurred:

- 71% at intersections
- 21% during lane changing manoeuvres.

In a multi-vehicle collision, as a percentage of recorded crashes, when the motorcyclist was at fault the following crash types occurred;

- 61% – rear end, motorcyclist had not left a large enough gap behind the driver
- 76% – head on, often as the result of going onto the wrong side of the road usually when negotiating a curve.

At T-intersections, 85% of the right-of-way-violations were caused by drivers who fail to give way to a motorcyclist. Right of way violations are commonly referred to as SMIDSY ('Sorry Mate I Didn't See You') in Australia, LBFS ('Looked but failed to see') or LBDNS ('Looked But Did Not See') in Europe, where the driver fails to detect the motorcyclist despite the driver having looked in the direction of the motorcyclist. The term 'Intentional blindness' is also used in the case, where the driver has an expectation of looking out for cars and other vehicles, but not motorcyclists. Poor conspicuity, where the motorcyclist is not highly visible due to their small profile, and driver distraction, are also explanations offered as the reason for right-of-way violations at T-intersections (Motorcycle Council of NSW 2010).

In a survey of around 1299 motorcyclists in NSW (de Rome & Brandon 2007), 42% of respondents reported that their actions leading up to the crash was taken in order to avoid a situation created by another vehicle, compared with 37% who reported being at fault through their own action/s, i.e. excess speeding for the conditions, lack of familiarity with their vehicles, fatigue, panic and failure to give way.

Group riding

NZTA (2012) asserted that group riding may be a contributory factor to the cause or severity of an incident involving a motorcycle due to the following reasons:

- Perceived or actual peer pressure for riders to ride above their abilities in order to 'keep up with the bunch'. This also includes inexperienced riders riding outside of their comfort zone or skill level.
- Lack of communication between riders.
- Desire to keep the group together, such as when stopping and leaving intersections or passing vehicles.
- Inappropriate riding formation.

The statistics showing the number of crashes occurring during group rides were not presented.

2.2.2 Contributory Crash Factors Relating to Road Infrastructure and Design

The road environment is reported to accounts for only 2% of motorcycle road deaths for all known single vehicle crashes between 1999 and 2003 in Australia (DITRDLG 2008). Although they may not be the cause of a crash, certain road elements have the potential to contribute to the actual outcome and severity of the crash.

Many motorcycle safety initiatives have been implemented by governments around the world that are targeted to address motorcyclist behaviour and attitude. Limited literature was found where road infrastructure changes or improvements were implemented to reduce the likelihood of a motorcycle crash occurring. The treatments that were identified were general and did not address all crash types represented in motorcycle crashes. Factors relating to injury prevention in various stages of a crash have been summarised in the Haddon Matrix in Table 2.4 (World Health Organization n.d). However, additional information needs to be included in the matrix to reflect the unique circumstances surrounding a motorcycle crash.

Table 2.4: Haddon Matrix

Phase		Human	Vehicles and equipment	Environment
Pre-crash	Crash prevention	Information Attitudes Impairment Police enforcement	Roadworthiness Lighting Braking Handling Speed management	Road design and road layout Speed limits Pedestrian facilities
Crash	Injury prevention during crash	Use of restraints Impairment	Occupant restraints Other safety devices Crash protective design	Crash protective roadside objects
Post-crash	Life sustaining	First aid skill Access to medics	Ease of access Fire risk	Rescue facilities Congestion

Source: World Health Organization n.d.

The following sections examine the road elements, such as roadside hazards, pavement condition and design, and geometry that are causation and contributory factors associated with the risk and the severity of motorcycle crashes.

Roadside hazards

Conventional roadside hazards contributing to the severity of motorcycle crashes include trees, roadside furniture (including barriers), slopes, buildings, embankments and culverts. To protect vehicles from these hazards, various types of roadside barriers are often installed at high risk locations (e.g. tight curves) and are designed to re-direct vehicles, sometimes even heavy vehicles, safely back onto the road or dissipate energy in a manner that would not harm the vehicle’s occupants. A vehicle will generally protect the occupants from directly impacting with the object, although some intrusions may occur.

Motorcyclists have a much greater risk of hitting objects directly, often after being destabilised. As a consequence of their design, some safety barriers could potentially pose a hazard to a motorcyclist in the event of a collision as the kinetic energy must be dissipated through the body of the motorcycle or motorcyclist rather than the barrier. If a motorcyclist collides with a safety barrier support pole the impact surface area is small and the crash force is concentrated on the point of impact.

As it is common for motorcyclists to slide along the road surface, exposed guardrail posts can prove to be especially dangerous (Koch & Schueler 1987). Accident analysis has shown that severe injuries are sustained by two out of three motorcyclists that collide with guardrails (Domhan 1987) with the most dangerous feature of guardrail systems being the guardrail posts.

Running off the road and colliding with a fixed object was reported by DITRDLG (2008) as having the highest fatality rate in single vehicle motorcycle crashes.

The most commonly struck 'known' objects were found to be:

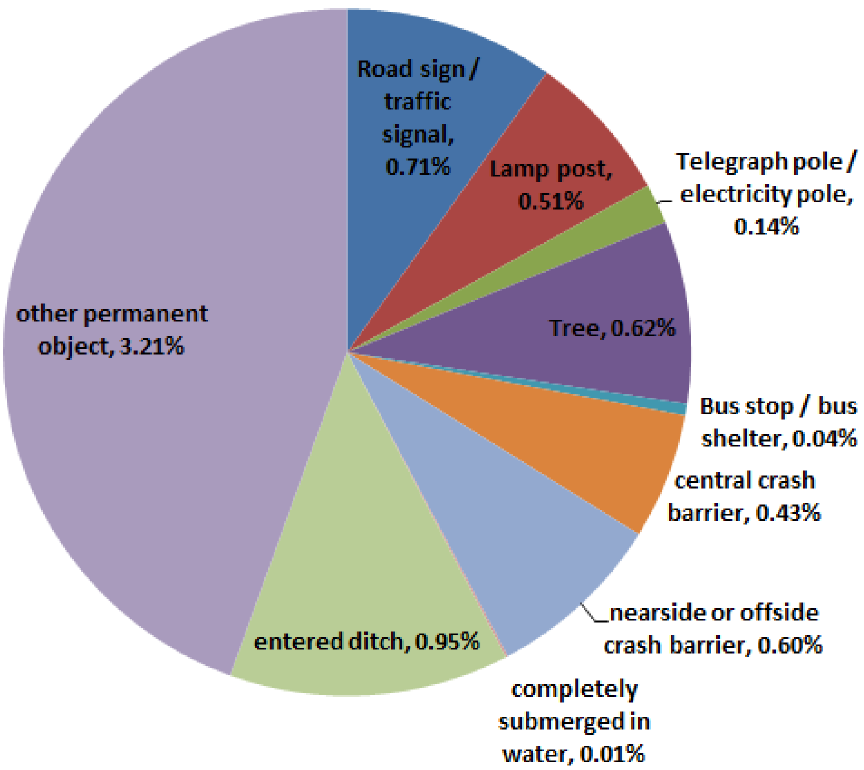
- trees (24%)
- fences (10%)
- street lights or traffic light poles (9%)
- drains or pipes (5%).

Roadside safety barriers contributed to:

- > 6% of motorcycle fatalities on all roads in Australia (Austroads 2012)
- 2% of fatalities on all roads in New Zealand (Austroads 2012)
- 13% of fatalities on rural roads in Europe.

A UK study found that objects hit off the carriageway accounted for 7.2% of the crashes and is shown in Figure 2.1.

Figure 2.1: Breakdown of objects hit off-carriageway (UK 2005-2007)



Source: 2-Be-Safe (2010).

For incidents where injuries are sustained that ultimately result in death, DITRDLG (2008) reported that for single vehicle crashes:

- 75% were impacts with other objects
- 13% were impacts with the road
- 5% were impacts with a vehicle exterior
- 6% were unknown or other.

For multiple vehicle crashes:

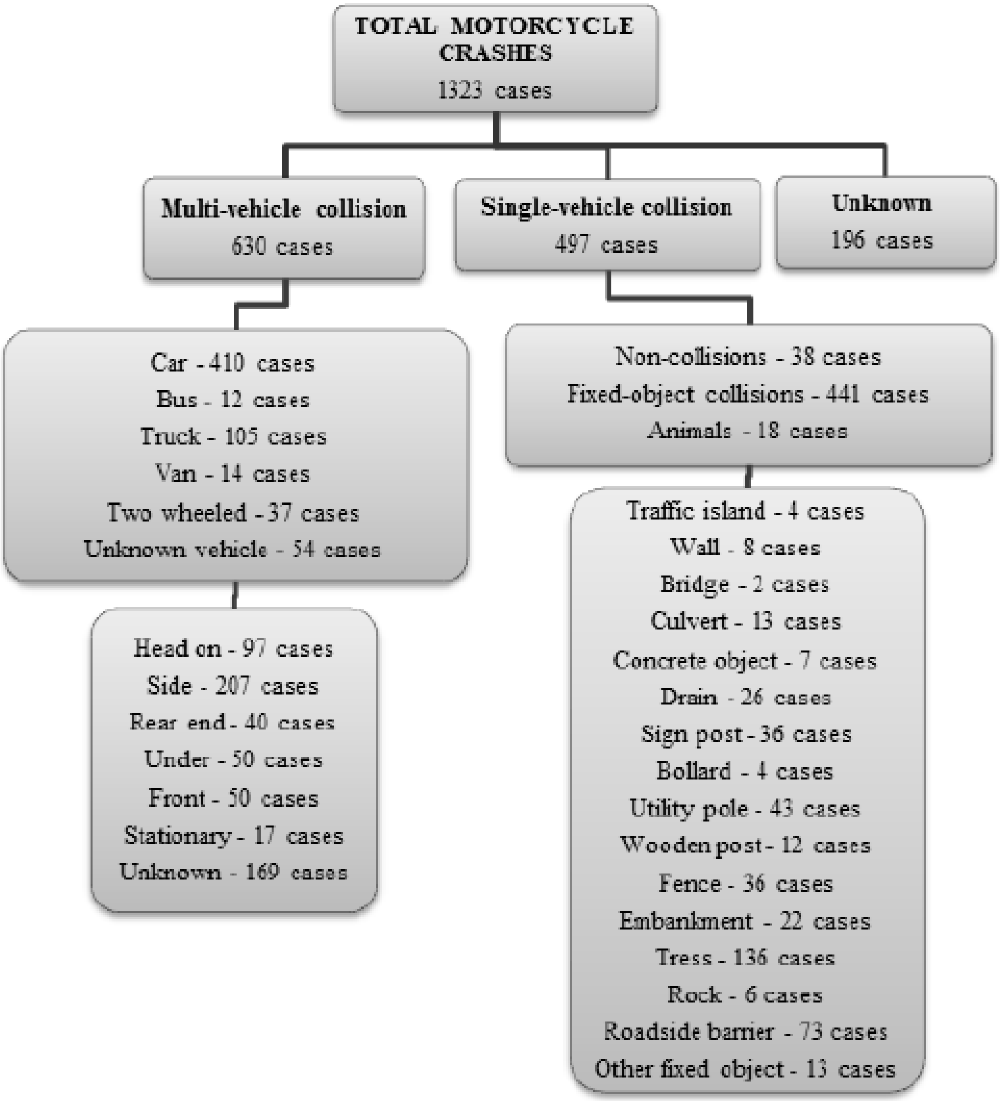
- 57% was due to impact with vehicle exteriors
- 16% were impacts with the road
- 12% were impacts with other objects
- 11% other and around 5% unknown.

A case study by Bambach et al. (2012) examined 1323 motorcycle fatalities in Australia, between 2001–06 using documents from the Australian National Coroner's Information System (NCIS) and found that 89% of the single-vehicle motorcycle crashes occurred when the riders collided with fixed objects by the roadside. The most frequent fixed object impacts were found to be:

- trees, 31%
- utility poles/posts, 21%
- roadside barriers, 17%, accounting for approximately 6% of all motorcycle fatalities.

The breakdown of the contributory factors for the 1323 fatal crashes in the study is shown in Figure 2.2.

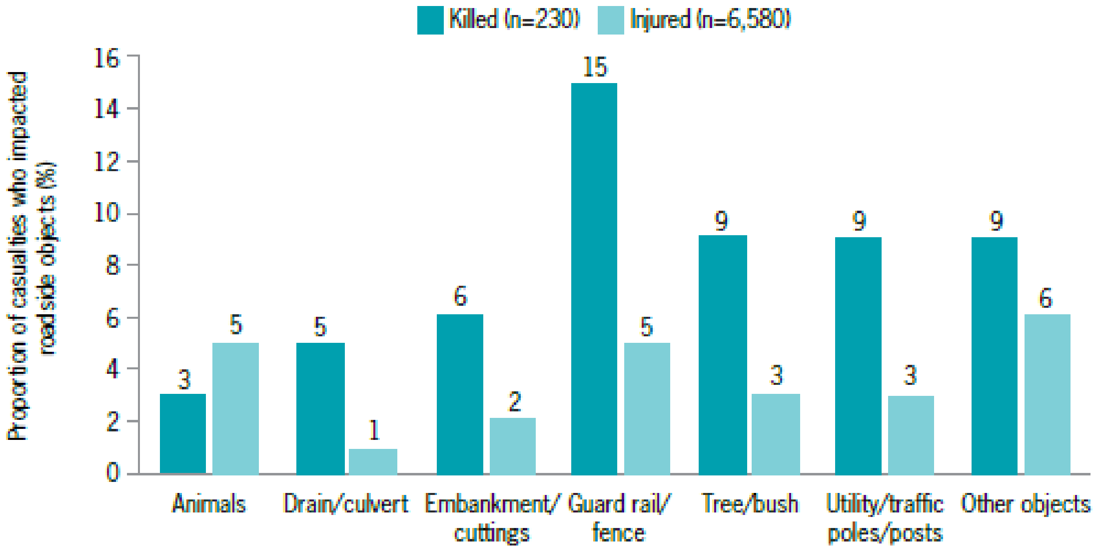
Figure 2.2: Crash events of fatal motorcycle crashes



Source: Bambach et al. (2012).

Motorcycle Council of NSW (2010) found that guard rails and fences (i.e. safety barriers) were the most commonly struck roadside object or fixed object in NSW with 8% of crashes involving roadside objects occurring with guard rails and fences, this resulted in a fatality for 15% of riders who struck guard rails or fences, as shown in Figure 2.3.

Figure 2.3: Motorcyclist casualties from impacts with roadside objects in single-vehicle motorcycle crashes, NSW, 2001-05



Note: Guard rail/fence is a generic term that is inclusive of all safety barrier types.
Source: Motorcycle Council of NSW (2010).

In Europe, wire ropes are more risky to motorcyclists in terms of road deaths compared to other barrier types. A study conducted by FEMA (2012) support this assertion with the following statistics for the proportion of fatalities relating to wire rope and other barriers:

- Scotland (1990–2005)
  - wire rope barriers, 100%
  - other barrier types, 58.3%.
- England (1992–2005)
  - wire rope barriers, 66.7%
  - other barrier types, 58.7%

The FEMA report does not conjecture why the fatality rates were so high nor why they differed between the two countries. Also the number of fatalities in each group was not provided, neither did it offer any insight on the exposure risks for the various barrier types.

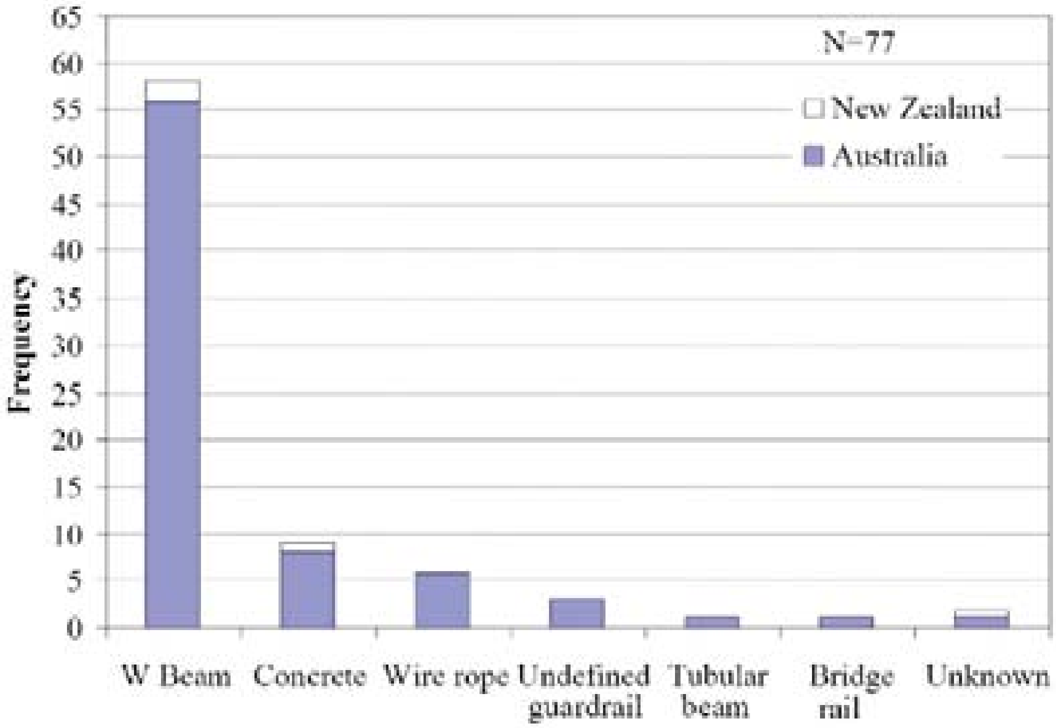
In contrast a recent study of motorcycle crashes with safety barriers in Australia and New Zealand (Grzebieta et al. 2010,) demonstrated that more fatalities resulted from collisions with steel barrier posts than with a concrete or wire rope safety barrier (Figure 2.4).

The percentage of motorcycle fatalities and respective proportion of installed safety barrier are as follows:

- W-beams 72.7% (71.5% of installed safety barriers)
- concrete barrier 10.4% (8.6% of installed safety barriers)
- wire ropes 7.8% (15.9% of installed safety barriers).

The study also stated that the majority of barriers installed on curved roads, where most of the motorcycle crashes occurred, were of a more traditional W-beam design. Typically manufactures specifications restrict wire rope safety barriers being installed on small radius curves (typically < 200 m). The performance of wire rope safety barriers on small radius curves, which are the most likely zones a motorcyclist will strike a safety barrier, is not included in the reported data.

Figure 2.4: Fatalities by safety barrier type



Source: IRMRC (2010).

The study also stated that the majority of barriers installed on curved roads, where most of the motorcycle crashes occurred, were of a more traditional W-beam design.

The review of the literature showed that roadside hazards were found be involved in a low proportion of motorcycle crashes (approximately 2–7%), however, when a roadside hazard was struck, the fatality rate was as high as 89% in some cases.

Pavement condition

Pavement conditions are known to affect the ability of motorcycles to stay upright through transmission of force via the contact patches on each of the tyres. A motorcycle is therefore far more susceptible to loss of control through reduced traction compared with four-wheeled vehicles. The literature identified road surface conditions as causal or contributory factors to motorcycle crashes, however the statistical evidence appeared to be inconclusive. Although it is perhaps intuitive to assume that road surface conditions would be play a critical role in motorcycle accidents, the results from studies conducted in Australia and internationally do appear to vary.

DITRDLG (2008) found that 91% of all single vehicle fatalities occurred on sealed/paved road surfaces. The figure was 95% for multiple vehicle crashes.

In New South Wales, between 2006 and 2010, single vehicle crashes made up 40% of motorcycle crashes. Road surface hazards, such as pot holes, oil on the road and loose gravel were implicated in 20% of single vehicle crashes, resulting in 9 fatal and 911 injury crashes for both urban and rural combined (Motorcycle Council of NSW 2013).

NZTA (2012) identified that in 8.5% of urban and 14.6% of rural motorcycle crashes, road conditions were implicated. This is highlighted in Table 2.5.

Table 2.5: Motorcycle/moped crashes on different road conditions in New Zealand from 2001 to 2010

Urban (percentage of crashes)	Rural (percentage of crashes)
Road slippery (including general and rain) 5.8%	Road slippery (including general and rain) 6.7%
Road slippery (loose material on seal) 1.6%	Road slippery (loose material on seal) 6.1%
Road slippery (oil/diesel/fuel) 1.1%	Road slippery (oil/diesel/fuel) 1.8%
Total crashes (8.5%)	Total crashes (14.6%)

Source: NZTA (2012).

Khoo and Stevens (2011) analysed the views of motorcycle focus groups in New Zealand and revealed a perception that bitumen binder rich surfaces, flushing and bleeding, reduces the skid resistance available for riders, regardless of weather conditions. It is likely that the crash statistics do not reflect this experience because the frequency of any crashes taking place is likely to have been too low to report.

The presence of road shoulders, their configuration and conditions have also been proposed as contributing to the severity of motorcycle crashes. DITRDLG (2008) was not specific about the level of exposure that motorcyclists may have had to different shoulder types, however it identified that shoulder surface was a relevant factor with:

- single vehicle motorcycle fatalities involving:
  - unsealed shoulders 57%
  - kerbs 32%
- multiple vehicles with motorcycle fatalities involving:
  - unsealed shoulders 58%
  - kerbs 25%.

Pearson and Whittington (2001) in WA stated that the lack of road markings coupled with poor visibility of kerbing can increase the chances of a motorcycle crash at night.

Pearson and Whittington (2001) reported that road surface grip, patch repairs, and road markings were considered 'the most important road surface factors' involved in motorcycle crashes, while gravelled (as compared with sealed road shoulders), slippery road markings, slippery man-hole covers/steel plates and uneven road surfaces presented a danger to motorcyclists. Potholes were also considered a 'significant causal factor in motorcycle crashes'.

The European 2-Be-Safe (2010) report discussed a study conducted in Austria that attempted to link road conditions (e.g. skid resistance, rutting) with motorcycle crash rates. It found that:

- More than 53% of motorcycle crashes on rural and inter-urban roads occurred on sections with a coefficient of friction (μ) > 0.75 ('very good').
- A high proportion of motorcycle crashes were also found to occur on roads with longitudinal evenness that was classed as average, at IRI (International Roughness Index) between 1.8 and 3, (41%). This is disproportionately high when compared with the occurrence of roads of this class (34%).

2-Be-Safe (2010) also showed that the highest occurrence of motorcycle crashes (58%) occur when the texture of the road, characterised by a Mean Profile Depth (MPD) is between 0.3 mm and 0.6 mm (i.e. a classification of 'poor'). The study states that road texture may be a more significant factor at motorcycle crash sites than skid resistance due to its effects on 'toothing' between the road surface (concrete, or asphalt) and the tyre.

The report recommends conducting tests to determine the side forces generated in accelerations and decelerations around curves to get an in-depth understanding of how texture affects the tyres.

Where rutting is concerned, 75% of all motorcycle crashes occur on roads classified as ‘good’ or ‘very good’ (i.e. rut depths ranging from 0 to 10 mm). However, the majority of Austria’s rural roads are classed as not having significant rutting.

The literature shows that where pavement conditions are concerned, there is a gap between what motorcyclists perceive as being a causal/contributory factor, and what the statistical evidence reveals. Factors such as skid-resistance and potholes are viewed by motorcyclists as a significant contributing factor but the literature from Europe and Australia does not corroborate those views.

The factors that were examined in the review, as being causal factors or contributing to the severity of a motorcycle crashes were:

- skid resistance and coefficient of friction
- unsealed shoulders
- kerbs
- potholes and rutting
- road texture (mean profile depth)
- roughness (longitudinal evenness)
- slippery roads (due to rain, loose material and chemicals)
- slippery road markings and man-hole covers.

Out of the factors mentioned above, only unsealed shoulders, kerbs, texture, roughness, and slippery roads were implicated in motorcycle crashes by statistics. It is a possibility that potholes and skid resistance does contribute to the destabilisation, skidding and crashes of motorcycles more regularly than the statistics would show. The severity of these events may be so low that they are often not reported to the police or road agencies and are therefore not captured in the statistics.

Pavement markings and delineation

NZTA (2012) stated the importance of consistent, well-located and skid resistant pavement markings to motorcycle safety. In practice, issues experienced by motorcyclists include:

- Absence of pavement markings.
- Slippery markings located in the centre of a lane or on curves that lead to low levels of skid resistance (i.e. large head directional arrows)
- Audio-tactile or raised markings placed within a lane or centrelines that may potentially cause motorcycles to ‘temporarily lose contact with the road surface’
- Faded road markings
- Transverse road markings.

Consistency in delineation and road signage is important in helping all road users, and specifically motorcyclists, ‘read’ the road ahead. Inconsistency or lack of signage, delineation, guide posts or edge markers can make it difficult for motorcyclists to anticipate and react to changing road geometry and conditions.

Intersections

Motorcycle crashes at intersections occur more commonly for multi-vehicle crashes than single vehicle crashes (DITRDLG 2008):

- motorcycle fatalities in multiple vehicle crashes:
  - 42% occurred within intersections
  - 58% occurred midblock
- single vehicle motorcycle fatalities
  - 7% occurred within intersections
  - 90% occurred mid-block.

The Motorcycle Council of NSW (2013) found that in multi-vehicle crashes in NSW involving motorcycles:

- 57% occurred at intersections
- 71% of intersection crashes was the fault of the other driver.

Human behaviour is used by the majority of the literature reviewed to explain the high rates at intersections of multi-vehicle crashes. This is elaborated on in Section 2.2.1.

For the European case, the 2-Be-Safe motorcycle project reports in great detail the relationships between crash rates and intersections.

The following shows the motorcycle crash rates in Spain for front to side accidents:

- urban areas:
  - for four way (X or +) intersections at 63%
  - three way (T or Y) at 28%
  - roundabouts at 8%
- express roads:
  - three way roads 49%
  - four way roads 34%
  - roundabouts 11%
- for rear end accidents:
  - outside urban areas 28%
  - inside urban areas 30%.

Crash rates for both rear end and front to side collisions at intersections occur are higher at intersections with no control.

In the UK, motorcycle 'incident count' is:

- 35.6% at T or 'staggered' intersections
- 8.8% at roundabouts
- 8.7%. at crossroads.

It was mentioned that 34.3% of motorcycle crashes did not occur at, or within, 20 m of an intersection. The most frequently reported type of impact at each intersection type was a head-on collision. The manoeuvre most likely to result in a crash at a T-intersection was overtaking a moving vehicle on its 'offside' (40%).

Horizontal curvature and alignment

The Bambach et al. (2012) study of 957 motorcycle fatalities found that:

- 39% occurred on curves (bends)
- 38% occurred at intersections
- 23% occurred on straight sections of the road.

The 2-Be-Safe project examined motorcycle crash risks on curves. The analysis involved plotting the relationship of Radius 1 (R1) against Radius 2 (R2), where R2 is the crash site onto a 'radii' tulip stating the inappropriate and good ranges for R1:R2. This technique was applied to seven federal road segments in Austria with high motorcycle exposure. It was found that a radii ratio larger than 1 (where the radius of the first curve, or a straight segment, is followed by a curve with a smaller radius) is dangerous. The most accidents occurred when R2 was smaller than 200 m.

Curves on descending grades were also associated with high motorcycle crash rates. A similar study in Spain aimed to find a relationship between the road geometry (radius of curvature, and crossfall) and the dynamics of the motorcycle (i.e. 'does an errant motorcycle ultimately leave the road upright or sliding on its side?'). The study found that crossfall and curve radius, when combined with approach speed, and 'not-predictable geometry' were all factors in run-off-road motorcycle crashes.

In Germany, an examination found that curvature change rate was higher on road sections deemed to be 'unsafe' than those deemed to be safe. The vast majority of crashes were found to occur on very small curve radii (< 50 m), likewise with curves and straight sections that were considered to have an 'unbalanced' ratio of successive radii, or radii adjacent to a straight.

Posted speed limits

Table 2.6 shows that the highest proportions of fatality crashes occurred on roads where the posted speed limit was 60 km/h (single vehicle crashes 32%, multiple vehicle crashes 34%). The next highest proportion of crashes occurred where the posted speed limit was 100 km/h.

Table 2.6: Posted speed limit for crashes involving the death of a motorcyclist between 1999 and 2003

Limit (km/h)	Single vehicle		Multiple vehicle	
	Count	% of known	Count	% of known
≤ 50	20	8	15	4
60	83	32	118	34
70	18	7	48	14
80	34	13	39	11
90	5	2	4	1
100	81	31	100	28
≥ 110	17	7	28	8
Unknown	140	-	162	-
All	**398**	**100**	**514**	**100**

Source: DITRDLG (2008).

Motorcycle braking systems

In addition to human and road design factors, the braking performance of Powered Two-Wheelers (PTWs) impacts on the severity and likelihood of an incident. Davoodi and Hamid (2013) found that under the same conditions the average braking deceleration rates in response to unexpected objects is less for PTWs than for passenger vehicles. This is attributed to motorcycles being inherently less stable and requiring riders to remain upright and stable in order to complete a deceleration manoeuvre. As a motorcycle is unstable, a rider will brake at a deceleration rate appropriate to their riding ability and road and weather conditions to ensure that the motorcycle stays upright. This may result in conservative braking thus increasing braking distances.

Technology such as Anti-lock Brake Systems (ABS) and Combined Lock Systems (CBS) offer additional stability by regulating the amount of brake pressure and linking the front and rear brakes in order to maintain traction. These systems are advantageous for PTWs when motorcyclists are inexperienced and in poor weather conditions.

In the event that a PTW is subject to an emergency situation, even the most experienced riders will struggle to brake optimally without the aid of a system such as an ABS. A less than optimal braking event could potentially lead to instability, locking of wheels, instability and an unavoidable loss of control and subsequent fall. Green (2006) concluded that riders did not require significant experience or skill to utilise the full braking performance and capability of PTWs installed with ABS, whereas for PTWs not installed with ABS, the braking performance varied greatly between trials as the rider was not able to utilise the maximum deceleration capacity of the PTW.

Green (2006) conducted a number of trials to measure stopping distance of a fully loaded PTW with and without ABS. The trials involved applying both front and rear brakes and were carried out in both wet and dry conditions with all other factors remaining constant. Table 2.7 summarises these findings.

Table 2.7: PTW stopping distance under different road conditions

Conditions	Speed (km/h)	Stopping dist. ABS (m)	Stopping dist. non-ABS (m)	Diff. (%)
Dry	48.3	12.51	14.90	19.1
Wet	48.3	13.28	15.35	15.6
Dry	128.8	78.00	93.33	19.7

Green concluded that PTW's showed an improvement in braking performance with the use of ABS, irrespective of a dry or wet surface. He also noted that without ABS, riders required numerous attempts to approach the maximum deceleration performance of the PTW whilst the ABS addition allowed the rider to quickly achieve consistent maximum deceleration results. He noted that an emergency braking manoeuvre is dependent on multiple factors (inclusive of operator experience) and it was clear from the testing that motorcycles equipped with an ABS would provide riders with a higher level braking performance during time of need.

Roll et al. (2009) analysed 51 accidents that occurred with PTWs not fitted with ABS, this analysis was carried out under the conditions that an ABS system would have been installed to show the difference in accident consequences of both situations. The study concluded that up to 50% of the selected accidents could have been avoided if an ABS was installed on the PTW. The authors concluded that this reduction is partly due to riders being able to apply maximum safe braking pressure and rely on optimal slip control in panic situations, resulting in reduced stopping distances.

This reduction in stopping distance could lead to lower collision speeds as the rider has increased time to react in a positive manner in the case of an unavoidable incident. Further, similar to the conclusion of Green (2006), the study concluded that the additional stability that an ABS provides allows the PTW to remain upright throughout the braking procedure rather than losing traction and falling to the road surface. This additional manoeuvrability and steerability of a PTW at low velocity allows the rider to more safely negotiate danger.

2.3 Treatments

Treatments aimed at reducing the risk of and severity of motorcycle crashes range from road design, treating roadside hazards and safety barriers, and informing riders of changing conditions on the roads up ahead through delineation, warning signs and alignment markers. The following sections provide a brief description of the various treatments available for improved motorcycle safety.

2.3.1 Roadside Hazards

Recognising the potential severity of motorcycle collisions with roadside barriers, the approach has been to:

- install flexible but durable materials or shields underneath barriers
- install attenuators or energy dissipaters on posts and poles
- relocate trees, poles, signs and other roadside objects if possible.

A number of case studies in Section 2.4 explore safety barrier treatments in greater detail.

2.3.2 Pavement Condition

Pavement and road surface conditions (i.e. ruts, cracks, loose gravel, etc.) were found to be a contributing factor in a low proportion of motorcycle crashes; however, unsealed shoulders, kerbs and road texture were identified in a high proportion of single vehicle motorcycle crashes. Defects in the pavement surface were not found to be a major contributing factor for motorcycle crashes nor have they been identified as contributing to the severity of a crash, however, varying skid resistance and uneven surfaces could cause the motorcycle to lose traction, while corrugations and ruts could unpredictably shift the tyre contact point with the road (Motorcycle Council of NSW (MCC) 2010).

Potholes can destabilise a motorcycle during a braking or turning procedure causing it to lose control. Crack sealant has low skid resistance and can present a problem. Rolling aggregates into the surface using specialised high skid resistance crack sealant is a recommendation for fixing it; however, if that is not possible, cracks by themselves do not represent an issue to motorcycles (Wood 2006).

Areas with flushing or polishing can have low skid resistance when wet. Polishing can exacerbate a situation as they may be in depressions in the road surface. Stripping and ravelling can result in loose gravel being swept into less travelled areas that motorcycles may need to use for emergency braking.

Loose gravel can cause wheels to suddenly lock, which can capsize the motorcycle. Rutting in the roads can cause a motorcycle to 'surf' from the crest of the rut into the valley, which may cause the motorcycle to veer from one lane to another. Depending on the degree, edge drops can prevent the safe re-entry of a motorcycle back onto the carriageway (Wood 2006).

A paper by Brian Wood (2006), the Chair of the Road Safety Committee for the Motorcycle Council of NSW suggests some levels of service for roads that would be amenable to motorcyclists based on his professional experience in asset management:

- Pot holes: where there are straight sections, potholes should not have a depth any greater than 25 mm or a dimension of more than 200 mm. Braking zones should have no untreated pot holes.
- Cracking: No crack width should be greater than 10 mm.
- Stripping and ravelling: Maximum of 40 loose stones per square meter for gravel resulting from new spray seal.
- Flushing and polishing: sections should not be longer than 2 metres, in braking zones and corners, skid resistance should not be less than 55 BPN (British Pendulum Number).
- Rutting: length of no longer than 4 m with a maximum depth of 50 mm.
- Edge drop: length of less than 5 m, depth of 30 mm.
- Shoving, settlement, heaving and corrugations: area no greater than 1.5 m^2 and depth no greater than 30 mm.
- Roughness Index: 1.5 IRI (m/km) to 6.0 IRI (m/km) with the smoother ratings in the braking and cornering zones.

The Federal Highway Administration (FHWA 2013) in the US recommends similar measures for dealing with pavement surface, although not to the extent of quantifying the levels of service:

- Patch potholes promptly. Potholes pose a greater hazard to the operation of motorcycles than to larger vehicles.
- Specify pavement surfaces with adequate pavement friction. Examine the friction characteristics of asphalt sealants and of intersection markings. The use of thermoplastics, particularly for broad, horizontal intersection lines, can create slippery surfaces for motorcycles that stop at the intersections. Metal road surface components – either temporary or permanent – offer limited traction in many cases, and, when wet, are difficult to see.
- Reduce uneven road surfaces. Milled surfaces, parallel paving lane joints, parallel grids on bridges, steel plates, and other uneven roadway surfaces can be especially hazardous for motorcycles.
- Require tidy crack repairs. A motorcycle's traction can be seriously compromised by 'tar snakes' – excess asphalt or other sealants used for crack repair.
- Remove debris and fluid spills quickly and thoroughly. Roadway debris and fluid spills pose greater hazards to the operation of motorcycles than to larger vehicles. Debris can deflect a motorcycle's wheel or hit the motorcyclist. Fluid spills can easily cause loss of traction.

Neither Wood, nor the FHWA reported on the effectiveness of these principles on reducing motorcycle crashes and crash severities. However, these principles and more were implemented in the Motorcycle Blackspot Program in Victoria (see Section 2.4.4). Since the program is still in its early stages, the results are still inconclusive. It is also a difficult task to accurately ascribe improvements in the crash occurrence to these measures alone.

2.3.3 Intersections

Multi-vehicle collisions involving motorcycles often occur at intersections. Where it is the fault of the other vehicle, the main factor identified has been obstructed visibility, i.e. vehicle at the intersection is unable to see a motorcyclist due to parked cars or another vehicle being in front of the motorcycle. Another issue is low conspicuity i.e. the driver looks but does not perceive the motorcycle.

There have been numerous studies in Melbourne and Europe that looked into the effects of implementing advance stop lines at intersections with filtering lanes for motorcycles to reach the front of traffic. A trial in NSW has begun where the space before an intersection is reserved for motorcycle parking in order to keep the area free of parked cars and improve the visible sight lines and the visibility of motorcyclists at intersections. The benefits of advance stop lines have already been demonstrated in Indonesia and Malaysia while road allocations in the form of designated motorcycle lanes have produced a 39% reduction in crash levels (MCC 2010).

2.3.4 Horizontal Curvature

The causal or contributory factors identified with road geometry are crossfall and curvature. Head-on collisions were found to be the most frequently occurring type of collision taking place in multi-vehicle accidents involving curves and run-off-road single vehicle accidents.

To assist motorcyclists when cornering, a principle known as 'the vanishing point' was devised by road engineers in Buckinghamshire, UK. The term was derived from the concept 'Where You Look is Where You Go' (WYLIWYG) on a motorcycle. By looking at a tree or a pole up ahead, a rider is more likely to hit that tree or pole; therefore the rider should look at the furthest point along a road which there is an uninterrupted view of the road surface. This point is known as the vanishing point.

The principle advocates improved curve delineation by the installation of guide posts up until the point where the vanishing point starts moving away from the rider's view into the straight. The effect ensures that the guide posts keep appearing into view, keeping the rider's attention into the bend and reducing the risk of them being distracted by other objects on the road side such as trees and poles. The study reports no motorcycle crashes occurred on a previously high risk curve since the principle was introduced (MCC 2010).

2.4 Case Studies

The following sections provide a brief description of case studies on motorcycle safety from Australia and Europe.

2.4.1 Case Study: Motorcycle Safety Route Review – New South Wales

Thomas et al. (2011) conducted a case study of a project undertaken by Roads and Maritime Services (formerly RTA) along Putty Road from Windsor to Singleton in New South Wales. The road is a 156 km stretch of rural road described as having 'steep batter slopes and rock walls, resulting in limited shoulder widths, and lengths of guardrails which did not always have adequate deflection behind it', curves of varying radii and alignments (constrained by the terrain) and regular overtaking opportunities. An 82 km section of Putty Road was targeted for treatment.

Putty Road is a two-lane road with an annual average daily traffic of slightly less than 1000 vehicles per day (in 2007 and 2011).

Prior to the treatments 55% of the crashes that occurred on Putty Road were motorcycle-related, while motorcycles only made up 5% of the traffic across the week.

Most of the crashes were found to occur on weekends, with 13.7% of the crashes attributed to motorcycles on Saturday and Sunday and only 3.7% on week days.

Between 2002 and 2007 there were 91 motorcycle crashes, with 77 injuries and 4 deaths, compared with 74 crashes for cars, 28 injuries and 4 deaths.

Crashes that occurred in daylight accounted for 98% of the crashes and 99% were in dry 'fine' condition. Weather and natural lighting were therefore determined not to be primary contributing factors in the crashes.

Single vehicle crashes accounted for 86% of motorcycle crashes, with 80% being run-off-road crashes and 76% involving guard rails. Analysis of the crashes between 1996 and 2010 determined that the main factors were speed related (71%). This was verified by speed surveys on two 100 km/h speed zones on straight sections of roads showing that higher rates of speeding was attributed to motorcyclists than other vehicles. It was difficult to identify whether some crashes were a result of changing curvature, as the police reports coded crashes to the nearest 500 m, 1 km or several kilometres from landmarks.

The treatments implemented included speed zoning, police enforcement, sign installation and line marking upgrades, delineation and campaigns to improve driver awareness. Speed zoning involved reducing a 14.8 km section of road from 100 km/h to 80 km/h, which also happened to be a winding road with the highest concentration of casualty crashes along the 82 km section. Banners, billboards and variable message signs were introduced to support the speed zone reductions, and police enforcement was implemented to increase awareness of speeds. Signs stating 'Motorcycle Safety Enforcement Areas next 50 kms' were installed along with seven police enforcement bays.

Some signs were upgraded with fluoro backgrounds at high crash risk locations, to improve the conspicuity of curve warning and speed advisory information, especially given varying light conditions in the vicinity. 174 chevron markers were installed along the study area and double unbroken lines were introduced through winding curves to limit overtaking opportunities on sections of the road with poor forward sight distance. Campaigns to improve driver awareness included banners and signs displaying messages such as 'Look out for motorcycles', 'Slow down on bends', 'Look out for yourself' and 'Plan your corners'. At rider rest areas, display cases were installed displaying RTA motorcycle information and resources.

The crash rates for three years after the treatments were presented as average crashes per year. There was a decrease from 12.3 per year to 10.3 per year for total non-motorcycle crashes, but a decrease of 15.2 per year to 10 per year for motorcycles. In this period there was one fatal crash compared with four for the six year period prior to treatment. Casualty crashes decreased from 12.8 per year to 9.3 per year and tow away crashes from 1.7 per year to 0.3 per year. On average, the crashes saved per year are significant for Putty Road with motorcycle crashes having decreased by a third which met the aim of the original project to reduce motorcycle crash rates. Roads and Maritime Services hope to implement this approach for other major motorcycle routes with high crash rates.

The following crash rates were established after remedial works: total crashes decreased from an average of 15.2 per year to 10.0 per year, 4 fatal crashes in 6 years to end 2007, 1 in following 3 years. Casualty crashes decreased from average 12.8 per year to 9.3 per year. Tow away crashes decreased from average 1.7 per year to 0.3 per year.

2.4.2 Case Study: Road Safety Barrier Treatments – South Australia

The Department of Planning, Transport and Infrastructure (DPTI) in South Australia (Anderson et al. 2012) identified roads and sections of roads with high motorcycle crash rates involving barriers. They installed barrier protection systems on existing barriers (Figure 2.5 and Figure 2.6) on Gorge Road and Cudlee Creek Road in the metropolitan Adelaide area on hilly terrain. Both roads are two lane, undivided and sealed with horizontal curves and safety barriers.

Figure 2.5: Installation and view of the flexible barrier protection system (see Section 1.4)

Source: Anderson et al. (2012).

Figure 2.6: Motorcycle protection steel rail

Source: Anderson et al. (2012).

Between 2001 and 2010, Gorge Road had 56 motorcycle casualty crashes resulting in 60 casualties (8 fatal, 21 serious, and 21 casualty). On Cudlee Creek Road in the same period 9 motorcycle casualty crashes occurred resulting in one fatality and 9 serious injuries.

Despite local analysis showing that only 6.5% of motorcycle crashes involved an impact with a barriers, treatments were targeted, given that motorcycles contribute 17% of total fatalities.

DPTI installed a flexible material (fabric mesh) below the guard rail which was designed to absorb human body impact against the safety barriers. The material used was a fireproof, recyclable, UV protected material that can perform at a wide range of temperatures, at a total installation cost of only $320 000. The treatment sites selected ranged from 50 to 200 m for a total length of approximately 1.4 km (based on location maps in the case study reference).

Motorcyclist friendly protection steel (under-run) was fitted to existing w-beam barrier. The installation cost was $150 000 and the sections installed ranged from 50 m to 700 m for a total length of approximately 4.0 km (based on location maps in the case study reference). The purpose of this countermeasure is similar to that of the flexible barrier: It provides protection to the motorcyclist from direct impact with the post barrier, and also prevents them from breaching the space between the barriers and interacting with the hazards that the barrier was designed to protect the road users from originally, such as trees or an embankment. As the under-run was designed to attach to European w-beam systems some bracket modifications were required to retro-fit it onto the older style w-beam systems with C-posts.

Post installation analysis (June 2010 to March 2012) showed 20 crashes along the road at the location, with 2 of these involving barriers. One of the crashes at the treated site was property damage only, and another, at an untreated site, was a minor injury. No fatal or serious injuries were recorded on both roads involving the barriers. A report in November 2010 of a crash on Gorge Road stated that a mature age rider slid into the flexible mesh barrier system after losing control of their machine in an attempt to avoid an opposing vehicle driving well over the centreline. The rider walked away with no injuries; however, there was considerable damage to the motorcycle. Further site investigations showed that there was minor damage to the barrier from other minor (but likely unrecorded) crashes.

The study noted a small number of limitations to the modified barrier system in that loose shoulder material on unsealed shoulders and residual tree bark and debris, which is a potential hazard to motorcyclists, tended to get collected by the fabric as there is little space underneath them for the debris to collect and be removed or dissipate. The barriers were also found to be susceptible to vandalism – sections were deliberated cut, thereby reducing their effectiveness to protect motorcyclists until a repair was effected.

2.4.3 Case Study: Motorcycle-friendly Barrier Systems – EuroRAP

The report ‘Barriers to Change: Designing Safe Roads for Motorcyclists’ (EuroRAP 2008), produced a set of recommendations made by its Motorcycle Safety Review Panel to address the lack of ‘safe’ road infrastructure specifically designed for motorcyclists. The report highlights that, in Europe, motorcyclists represent 16% of the overall road fatalities, yet only 2% of the total distance travelled. It was also found that barriers were found to contribute to the severity of motorcycle crashes, with ‘serious injuries’ being reported for barriers (66%), trees (59%) and pavements (19%). As a result, the report’s main emphasis is on European test standards, or more accurately a lack thereof, for crash barriers that take motorcyclists into consideration.

Three categories of barrier treatments for motorcyclist safety were identified: secondary rail systems, protection for support posts and barriers designed with motorcyclist safety incorporated. All of these are reactive measures, and possibly with limited engineering evidence to support their design.

Secondary rail systems (with commercial names such as BikeGuard, Moto.Tub, Plastrail, Motorail and Shield) are metal rails or plastic tubes that fit below the existing barrier, preventing riders from sliding horizontally under beams and offering protection from metal support posts. France pioneered the use of these systems in 2000, when secondary rails were retrofitted to barriers on high risk crash sites across the nation with preliminary evaluations predicting a halving of motorcyclist deaths caused by barriers. The report cites research showing that when implemented in areas where shallow angle collisions were likely, these treatments could half the number of fatalities for motorcyclists. However, testing in Germany has found that the secondary rail systems can adversely impact cars with an increased risk of them mounting the barrier.

The design and protection of safety fence posts were meant to mitigate the severity of collisions into these components, given they are judged to be ‘particularly aggressive’, irrespective of the barrier type adopted.

I-shaped posts, traditionally implemented across Europe, are being replaced with Σ-shaped versions that are thin-walled and have rounded edges. The Σ-shaped posts have been shown to result in bruising to a displaced rider, whereas I-shaped posts were shown to slice through helmets, with immediate fatal consequences.

Impact attenuators only cover individual support posts rather than offer continuous protection along the length of the barrier, but remain a cheap and effective treatment, estimated to save 25% of all motorcycle fatalities and halving crash severity. Spain currently pioneers the testing and standardisation of post-impact protectors.

The EuroRAP report presents the viewpoint that although there are many anecdotal evidence and real world demonstration projects suggesting that ‘powered-two-wheeler’ friendly add-on products (i.e. secondary rails and impact attenuators) are likely to reduce the severity of motorcycle crashes, the lack of casualty data and ‘evidence of causation’ puts engineers in a position of having to make critical decisions regarding treatments for motorcycle safety, without access to complete data. The report thus recommends further investigations into these treatments while installation of one or more motorcycle-friendly systems, based on the results of benefit-cost analysis, to continue until better systems are developed. It also stipulates the need for a technical design manual that includes clear procedures for implementing site and route appropriate systems on existing and new roads.

The Panel also presented the following recommendations for the interim period, until changes to the European testing standards are implemented (this list is not exhaustive):

- Identification of routes most frequented by PTWs in establishing risk is necessary. This will produce a more realistic view of what can be achieved by engineering countermeasures.
- Systematic collation of crashes involving PTWs to identify the true scale of the problem is required. When collisions involving barriers are recorded, the nature of the barrier and circumstances under which it was struck must be included as standard.
- Projects demonstrating the pre and post-implementation of motorcycle-friendly devices under real world conditions should be encouraged and collated.
- Every road safety engineering department should have a ‘motorcycle champion’ to introduce cultural change to the way in which risks are viewed from a road agency perspective.

2.4.4 Case Study: Motorcycle Blackspot Program in Victoria

Victoria implemented the Motorcycle Blackspot Program (MBP) in 2003, building on the success of its wider Blackspot program, but to focus entirely on sites or segments of roads with high motorcycle crash rates, with the intention of treating them to reduce the crash risks for motorcycles. To date, 130 locations had been treated (Brennan & Beer 2007).

Sites that were targeted for treatment have to meet certain crash criteria. Loss-of-control Sites are three types of sites that have different criteria for loss of control and casualty crashes as outlined below:

- The metropolitan 'black lengths' must have at least three, loss-of-control motorcycle casualty crashes and a crash rate of two motorcycle casualty crashes per kilometre over a five year period.
- Rural 'black lengths' must have at least three loss-of-control casualty crashes and a minimum of 0.5 casualty crashes per kilometre over a five year period.
- Black spots (metropolitan and rural) require a minimum of 3 loss-of-control motorcycle casualty crashes over a five year period to be eligible for the MBP.

Intersection sites require a minimum of three motorcycle casualty crashes over a five year period, and *Long Routes* are those with the proportion of motorcycle casualty crashes exceeding 11% of all casualty crashes.

The treatments developed under the MBP aimed to:

- **Enhance sight lines and delineation:** plantings, poles or fixed objects on the roadside are removed or relocated. No parking zones adjacent to intersections are extended. Lights or improved road delineation, particular edge lines, flexible guide posts and chevron alignment markers are installed.
- **Control vehicle speed:** may include geometric modifications, installation of warning and speed advisory signs and measures that may be implemented to reduce vehicle speed to safe levels at intersections.
- **Improve road surface:** such as improving skid resistance, correcting road camber, relocating drains, correcting level of service pit covers, repairing rough edges, replacing hazardous surface materials such as stone pitchers.
- **Reduce risk of crashes with fixed roadside objects**: may include sealing bell mouths (intersection and shoulders to provide safe run off areas for motorcyclists to recover from errors, and prevent gravel from moving onto the road. Removal or relocation of hazardous objects may also be necessary, along with the substitution of roadside furniture that presents less of a hazard to motorcyclists such as frangible poles, road signs, and flexible delineators on crash barriers.
- **Provide effective signage or controls:** may include on-road markings and roadside signage. Traffic signal phasing may need to be adjusted to enable traffic to clear the intersection in good time.
- **Manage traffic flows:** prohibit right hand turns, install traffic lights to guide right turning traffic or installation of advanced warning signs to enable riders to perceive intersection or road conditions (e.g. to facilitate lane change).

An evaluation of the MBP by MUARC (Scully et al. 2008) based on 87 treated sites reported a 24% reduction in casualty crashes for motorcycles and a 16% reduction for all other crashes. The study further reports the effectiveness of each type of treatment used in the program.

Site limitations at intersections and on 'black lengths' were noted by experienced motorcyclists and treatments to mitigate the risks were applied.

The following gives the limitations and problems listed for the black length projects:

- slippery or uneven surface
- obstruction of sight-lines when entering curves
- roadside hazards
- poor delineation of curves
- insufficient warning signs
- hilly terrain and steep drop offs.

The following treatments were commonly used to treat ‘black lengths’:

- removal of roadside hazards
- resurfacing
- sealing or repairing shoulders
- hazard removal including extending culverts or installing culverts with rideable end walls
- line-marking and installing raised reflective pavement markers
- improving warning signs or installing advisory speed signs
- installing chevron alignment markets (CAMs) and guideposts
- clearing the road surface of debris.

Less commonly used black length treatments, mainly undertaken to prevent run-off-road crashes, included:

- curve widening (widening the formation width on the curve only, however not greater than max. lane and shoulder widths)
- addition of rub rail2 to existing guard rail
- installation of guard rails and safety fences
- installation of frangible poles and lightweight signs
- improved street lighting.

The study reported only one intersection was treated as part of the MBP program, and the main issue was the design which allowed illegal traffic manoeuvres, resulting in dangerous conflicts between road users. The intersection which had zero casualty crashes occurring post treatment where there were eight crashes pre-treatment.

However, Scully et al. 2008 suggested that a longer post-treatment period was necessary to accurately estimate the effectiveness of the intersection treatment site. The pre-treatment data was for six years while there were only two years of post-treatment data.

Over long routes the aim is to make the road/route more consistent and predictable for the riders.

The following treatments were commonly implemented along the 18 sites treated using long route treatments:

- curve alignment markers (CAMs) on all curves
- warning signs and advisory speed signs
- frangible guideposts at consistent intervals
- line marking over the entire length of the road
- re-evaluation of the speed advised on signage approaching bends using GIPSITRAC road geometry data.

It was found that the black length treatments corresponded with a significant 40% reduction in motorcycle crashes, as well as a 24% overall reduction in casualty crashes for all other types of vehicles.

It is suggested that the results for the long route treatments were slightly ambiguous due to the results producing statistically insignificant and slightly negative readings. This could have been the result of statistical variation in the data rather than the representation of an actual increase in crashes.

[2] Rub rails are fitted to W-beam guard rails to shield motorcyclists from impacting supporting posts of safety barrier systems. They present a smooth, continuous surface without sharp edges or snag points can be positioned between the w-beam rail and the ground line.

2.4.5 Case Study: Motorcycle Blackspot Program in Victoria – Update July 2015

Victoria implemented the Motorcycle Blackspot Program (MBP) in 2003, building on the success of its wider Blackspot program, but to focus entirely on sites or segments of roads with high motorcycle crash rates, with the intention of treating them to reduce the crash risks for motorcycles. As of 2007, 130 locations had been treated (Brennan & Beer, 2007).

A total of 176 treatments have been installed since 2003. These were revaluated in a study conducted in 2015 (Cairney et al. 2015). The 176 treatments included: 9 barrier protection treatments, 4 intersection treatments, 61 long route treatments, 92 loss-of-control treatments, 4 roundabout trial treatments and 6 variable message sign trial treatments.

The crash reductions and their significance were estimated by fitting a mixed generalised linear negative binomial model with sites nested within sub-programs. This procedure takes into account changes in the number of crashes at the control sites, an essential step since there was an upward but fluctuating trend in motorcycle travel over the life of the program. Statistically significant crash reductions were found for the program overall with an estimated 27% reduction in casualty crashes (Table 2.8) and an estimated 31% reduction in fatality and serious injury crashes (Table 2.9) after adjustment for changes at the control sites.

Table 2.8: Casualty crash reduction

	Treatment			Control (*)			Statistic	Significance	Estimated adjusted crash reduction
	Before	After	% reduction	Before	After	% reduction			
Barrier protection	12	9	25	35	48	–37	F(1,44) = 2.342	.133	26%
Intersection	13	6	54	64	68	–6	F(1,12) = .740	.407	49%
Long route	655	478	27	84	100	–19	F(1,160) = .499	.481	32%
Loss of control	292	189	35	609	630	–3	F(1,295) = .741	.390	33%
Roundabout***	3	8	–167	13	10	30	F(1,15) = 3.587	.078	No reduction
VAS	10	11	–10	13	6	54	F(1,16) = .177	.680	No reduction
Program as a whole**	985	701	29	818	802	5	F(1,520) = 59.86	<.001	27%

** Sites matched for all sub-programs except Long Route.*
*** Nesting within subprograms and sites.*
**** Treat results with caution due to small numbers.*
Minus sign indicates an increase in crashes.

Table 2.9: Fatal and serious crash reduction

	Treatment			Control (*)			Statistic	Significance	Estimated adjusted crash reduction
	Before	After	% reduction	Before	After	% reduction			
Barrier protection	8	4	50	11	25	127	F(1,44) = 26.42	<.001	74%
Intersection	9	2	78	35	25	4	F(1,12) = 1.941	.189	69%
Long route	380	262	31	53	55	12	F(1,160) = .415	.520	29%
Loss of control	153	92	40	240	269	–29	F(1,296) = 1.397	.238	42%
Roundabout	3	5	–67	6	5	17	F(1,15) = .016	.901	–3%
VAS	3	6	–100	6	3	50	F(1,16) = .450	.512	No reduction
Program as a whole **	556	371	33	371	385	–10	F(1,520) = 44.82	<.001	31%

** sites matched for all sub-programs except Long Route.*
*** nesting within subprograms and sites.*
Minus sign indicates an increase in crashes.

When the different treatment types were considered separately, there were substantial crash reductions although only one of these was statistically significant. This was the barrier protection treatment, which produced a highly significant reduction of 74% in FSI crashes.

Results for the other treatments were highly variable from site to site; results were not statistically significant, but the FSI crash reductions were substantial in the case of the long route and loss-of-control sites, 29% and 42% respectively, while the intersection sites showed a 69% reduction although the numbers were much smaller.

The most frequent crash types at the long route treatment sites, before and after installation, are shown in Table 2.10, along with the percentage reduction achieved. Substantial reductions were achieved in head-on crashes (DCA 120), and in all the DCAs indicating leaving the road or losing control on a curve (DCAs 180, 181, 182, 183 and 184). Since these are the types of event the long route treatment was designed to address, these results suggest the treatments are well targeted.

There was also success in reducing right-through crashes (DCA 121) and collisions with animals (DCA 167), results which are consistent with reduced speeds.

Table 2.10: Reductions in most frequent types of motorcycle casualty crashes at long route sites

DCA	Description	N before	N after	% reduction
120	Head-on	62	44	29
121	Right through	17	6	65
130	Rear end	12	13	–8
167	Animal (not ridden)	26	18	31
170	Off carriageway to left	13	6	54
174	Out of control on carriageway on straight	36	48	–33
180	Off carriageway right bend	86	48	44
181	Off right bend into object	90	61	32
182	Out of control on carriageway – off right bend into object	64	29	55
183	Off left bend into object	62	35	44
184	Out of control on carriageway – on curve	76	73	4

A generally similar pattern was observed at the loss-of-control sites, this is shown in Table 2.11. There were substantial reductions in head-on crashes and right-through crashes (DCAs 120 and 121), although the numbers are small in the latter case. All the DCAs indicating leaving the road or losing control on a curve (DCAs 180, 181, 182, 183 and 184) showed moderate to large reductions. One difference with the long route treatments is that in this case, the out-of-control on carriageway on straight category was also reduced (DCA 174). Once more, these results suggest that the program has been well-targeted.

Table 2.11: Reductions in most frequent types of motorcycle casualty crashes at loss of control sites

DCA	Description	N before	N after	% reduction
120	Head-on	40	27	33
121	Right through	10	3	70
174	Out of control on carriageway	44	29	34
180	Off left bend into object	28	18	36
181	Off right bend into object	36	19	47
182	Right off carriageway on straight and into object	27	9	67
183	Off carriageway left bend	29	20	31
184	Out of control on carriageway	31	21	32

The program also showed good economic returns. When considered in terms of motorcycle casualty crashes, the BCR was between 6.3 and 7.6 and has an NPV of between $170 million and $211 million, depending on the assumed discount rate. When considered in terms of motorcycle FSI crashes, the BCR was between 7.1 and 8.5, and the NPV was between $195 million and $240 million. The cost of the program has been just under $32 million.

The barrier protection program has been particularly effective in reducing FSI crashes (by 74%), and shows the best economic returns.

The long route treatments and the loss-of-control treatments have both been successful in reducing crashes and show good economic returns. In both cases, sufficient numbers of sites have received the treatments to allow confidence in the results.

The intersection treatments also showed good reductions in motorcycle crashes, but the number of sites is small; although the BCRs are lower than for other treatments, they still indicate a good return on investment. While this treatment is positive, it needs to be trialled at more sites before full confidence can be placed in it.

Neither the trial roundabout treatments nor the trial VAS treatments resulted in crash reductions.

2.5 Conclusions

From the literature motorcyclists are five times more likely to be involved in a fatal crash than a vehicle occupant. This is significant given that motorcyclists account for less than 5% of vehicle registration.

Majority of motorcyclist crashes occurred in clear weather conditions on dry road surfaces. Weekends saw a concentration of fatal motorcyclist crashes (approximately 50%), these mainly occurred during recreational riding. There is also an assertion that group riding may be a causal or contributory factor to the severity of motorcycle crashes, which may be the result of lack of communication between riders, peer pressure (perceived or actual) for riders to ride above their abilities, desire to keep the group together and inappropriate riding formation.

Within Australia the highest proportion of motorcycle fatalities occurred on curves (39%), intersections (38%) and straight roadways (23%). Crossfall, curve radius, grade, approach speed and ‘non-predictable geometry’ have all been found as contributory factors in motorcycle crashes.

Australian studies had mixed results when linking crashes to locations and road types. The key points that were apparent were between 40–60% of multi-vehicle crashes occurred in urban areas, 28% of single vehicle crashes on major arterial roads (including highways) and single vehicle crashes were more common in rural areas. The review also found that the highest proportion of fatalities occurred on roads with posted speed limits of 60 km/h for both rural and urban areas (32% for single vehicle and 34% multiple vehicle crashes respectively) followed by 100 km/h (31% for single vehicle and 28% multiple vehicle crashes respectively).

Motorcycle fatalities in multi-vehicle and single vehicle crashes often occurred on midblock sections (58% and 90% respectively) however, multi-vehicle crashes were more likely to occur within intersections (58%) than on midblock sections (7%).

Single vehicle motorcycle crashes were more predominantly off-carriageway curves (34% right bend, 23% left bend) and next most significant was off-carriageway on straights (22%). Multi-vehicle crashes where the motorcyclist was at fault were predominantly head-on, followed by a motorcyclist rear-ending the vehicle in front.

Human factors have a significant contribution to single and multi-vehicle crashes. In a single vehicle crash, motorcyclists were often found to have been travelling at excessive speeds (70%), at times while impaired by drugs and/or alcohol (46%) or a combination of both. In a multi-vehicle crash, the party often at fault is the other vehicle (38%) compared to the motorcyclist (22%). Some studies identified that at T-intersections, 85% of the right of way violations were caused by drivers failing to give way to a motorcyclist.

The road environment was identified as the main factor in only 2% of single vehicle crashes involving motorcycle deaths between 1999 and 2003 in Australia. However, road environment is a major factor in the severity of these crashes when they do occur. Roadside hazards and road conditions may not directly cause the crash however colliding with roadside hazards is common, accounting for 75% of single vehicle collisions and 57% of multiple vehicle fatal crashes. The most commonly struck objects:

- trees (24–31%)
- fences/safety barriers (10–12%) – safety barriers contribute to over 6% of motorcycle fatalities in Australia
- street lights or traffic light poles (9%)
- drainage and drain pipes (5%).

Other road-related factors that contribute to motorcycle crashes include:

- poor surface grip and road surface hazards such as pot holes, oil on the road, loose gravel and patch repairs
- Poor or lack of consistent delineation (including pavement markings, line markings, and signage), especially on curves
- poor road surface texture, with a Mean Profile Depth of between 0.3 and 0.6 mm
- unsealed shoulders and kerbs were relevant factors in both single vehicle and multiple vehicle crashes
- audio-tactile or raised markings may cause the motorcycle to ‘temporarily lose contact with the road surface’.

Treatments and measures that can be applied to reduce the likelihood of a motorcycle crash and the severity include:

- consistent, well located and skid resistant pavement surfaces and markings
- improved delineation especially on curves (including line markings, guide points and road signage) enable motorcyclists to ‘read the road ahead’ and adjust speed appropriate for the road geometry. This reduces the need for emergency braking and swerving
- provision of motorcycle friendly barriers
- improved intersection control through the provision of s advance stop lines at intersections with filtering lanes for motorcycles to reach the front of traffic
- anti-lock braking systems may help the motorcycle to maintain traction with the road and mitigate the risk of crashing due to rider inexperience, poor road surface, and weather conditions
- ABS systems can reduce motorcycle stopping distances for both wet and dry conditions, and provide motorcyclists with a higher level of braking performance.

3. Crash Analysis

An analysis of injury crashes (including fatal crashes) was undertaken to examine the relationship between road infrastructure and motorcycle crashes. A high level comparison between motorcycle and passenger vehicle crashes was also undertaken.

The analysis examined crash data for a ten-year period. As the analysis was undertaken at a high level to identify infrastructure and crash relationships, three jurisdictions were analysed. The three jurisdictions that had sufficient motorcycle crash data and were considered to best represent motorcycle routes for recreational and commuting riding were:

- Department of Transport and Main Roads Queensland (TMR)
- Department of Planning, Transport and Infrastructure South Australia (DPTI)
- NZ Transport Agency (NZTA).

Due to the procedural differences in treating property damage only (non-injury) crashes by different jurisdictions, the analysis was focused on fatal and injury crashes only.

Casualty crash data was provided by the Australian jurisdictions and data was sourced from New Zealand's Crash Analysis System (CAS).

The analysis compared vehicle crashes and motorcycle crashes. A vehicle crash was defined as a crash involving all vehicles other than motorcycles. A motorcycle crash was defined as a crash involving a motorcycle and vehicle, or a motorcycle only.

The following were investigated:

- Overall crash rates
- Injury crash rates
- Comparison of multiple and single vehicle crashes and crashes involving motorcycles
- Commuting and recreational period crashes
- Relationship between road features and crashes
- Relationship between crashes and horizontal and vertical geometry
- Comparison of crash types (crash nature, DCA code or movement code).

3.1 Summary of Crash Rates

The crash rates for motorcycles and vehicles are summarised in Table 3.1.

Queensland (QLD) and New Zealand (NZ) have similar motorcycle injury crash rates, whereas the motorcycle injury crash rate in South Australia (SA) was significantly higher.

Table 3.1: Motorcycle and other vehicle crash rates

Jurisdiction	TMR (QLD)	DPTI (SA)	NZTA (NZ)
	2002–11	2001–10	2001–10
Total number of crashes (fatal, injury and property damage)			
All crashes (vehicles and motorcycles)	218 372	261 503	383 766
Vehicle only	202 068	254 222	372 402
Involving motorcycle	16 304	7281	11 364
Motorcycle crashes as a percentage of total crashes	7.47%	2.78%	2.96%
Injury crashes (fatal and injury only)			
Passenger vehicle only	123 024	57 306	98 758
Involving motorcycle	16 017	5 284	10 176
Motorcycle crashes as a percentage of all injury crashes	11.52%	8.44%	9.34%
Annual total VKT (million) – 2010			
Passenger vehicle	45 369	13 754	39 570
Motorcycle	631	124	360
% annual motorcycle VKT	1.40%	0.90%	0.90%
Crash rate (crashes/million VKT)			
All crashes	0.47	1.88	0.96
Involving motorcycle	2.58	5.87	3.16
The difference between motorcycle and all crashes rate	2.11	3.99	2.2
Injury crash rate (crashes/million VKT)			
All crashes	0.30	0.45	0.27
Involving motorcycle	2.54	4.26	2.83
The difference between motorcycle and all crashes rate	2.24	3.81	2.56

3.1.1 Overall Crash Rates

The analysis shows that:

- For all crashes (vehicle and motorcycle):
  - the overall crash rates for all vehicles for the three jurisdictions ranged from 0.47–1.88 crashes per million VKT
- For motorcycle crashes only:
  - the crash rates for motorcycles for the three jurisdictions ranged from 2.58–5.87 crashes per million VKT
  - motorcycle crash rates were generally 3–5 times higher than the crash rate for all vehicles
  - Queensland had the lowest overall and motorcycle crash rates, whereas South Australia had the highest.

3.1.2 Injury Crash Rates

The analysis shows that:

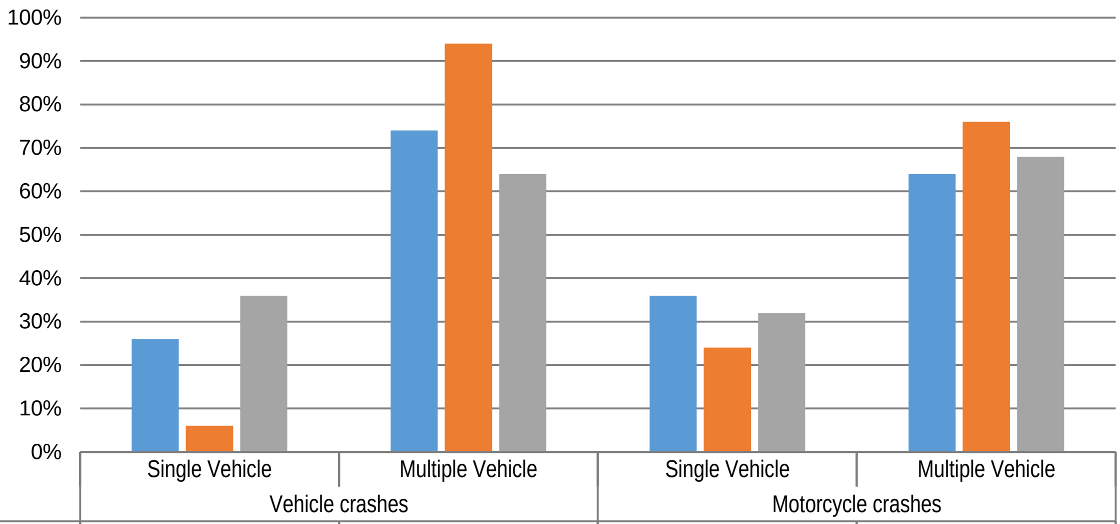
- For all crashes (vehicle and motorcycle)
  - the injury crash rates for all vehicles for three jurisdictions ranged from 0.27–0.45 crashes per million VKT
  - New Zealand had the lowest overall injury crash rate, whereas South Australia had the highest
- For motorcycle crashes only:
  - motorcycle injury crash rates for three jurisdictions ranged from 2.54–4.26 crashes per million VKT
  - motorcycle crash rates were generally 8–10 times higher than the crash rate for all vehicles
  - Queensland had the lowest motorcycle injury crash rate and South Australia had the highest.

3.2 Multiple and Single Vehicle Crashes

For crashes involving only vehicles (vehicle crashes) or a vehicle and a motorcycle or a motorcycle only (motorcycle crashes), Figure 3.1 shows that:

- For vehicle crashes, significantly more multiple vehicle crashes occurred than single vehicle crashes.
- For motorcycle crashes, more multiple vehicle, motorcycle crashes occurred than motorcycle only crashes.
- The proportion of single vehicle, motorcycle only crashes was higher than the proportion of single vehicle, vehicle crashes (excluding NZ where the rates where similar).

Figure 3.1: Vehicle and motorcycle crashes involving single or multiple vehicles by jurisdiction



	Vehicle crashes – Single Vehicle	Vehicle crashes – Multiple Vehicle	Motorcycle crashes – Single Vehicle	Motorcycle crashes – Multiple Vehicle
Queensland	26%	74%	36%	64%
South Australia	6%	94%	24%	76%
New Zealand	36%	64%	32%	68%

Note: Crashes are distributed by the number of vehicle or motorcycle crashes each jurisdiction. The vehicle or motorcycle crashes shown for each jurisdiction in total equal 100%.

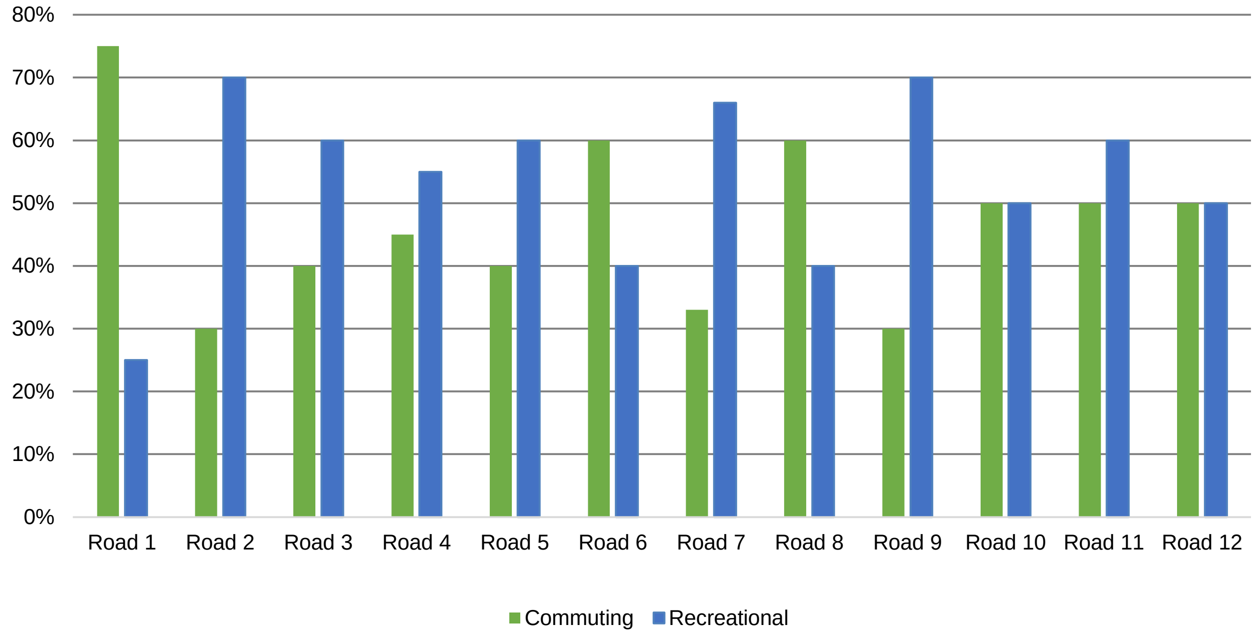
3.3 Commuting and Recreational Travel Crashes

Any crashes that occurred during Monday to Friday, excluding public holidays, i.e. working days, were defined as commuting period crashes. Most jurisdictions have approximately 250 working days in a year, i.e. approximately 68% of all days in a year.

Any crashes that occurred on Saturday, Sunday or on a public holiday were defined as recreational period crashes.

A crash analysis for a series of Motorcycle Specific Road Safety Audits undertaken by ARRB Group (Milling & McTiernan 2014) on 12 rural connector roads showed that crashes during the week (commuting period) where proportionate to the number of crashes on the weekends (recreational period) on some roads (Figure 3.2). This indicates motorcycle crashes are distributed across both travel purpose periods.

Figure 3.2: Motorcycle crashes by crash period on rural connector roads



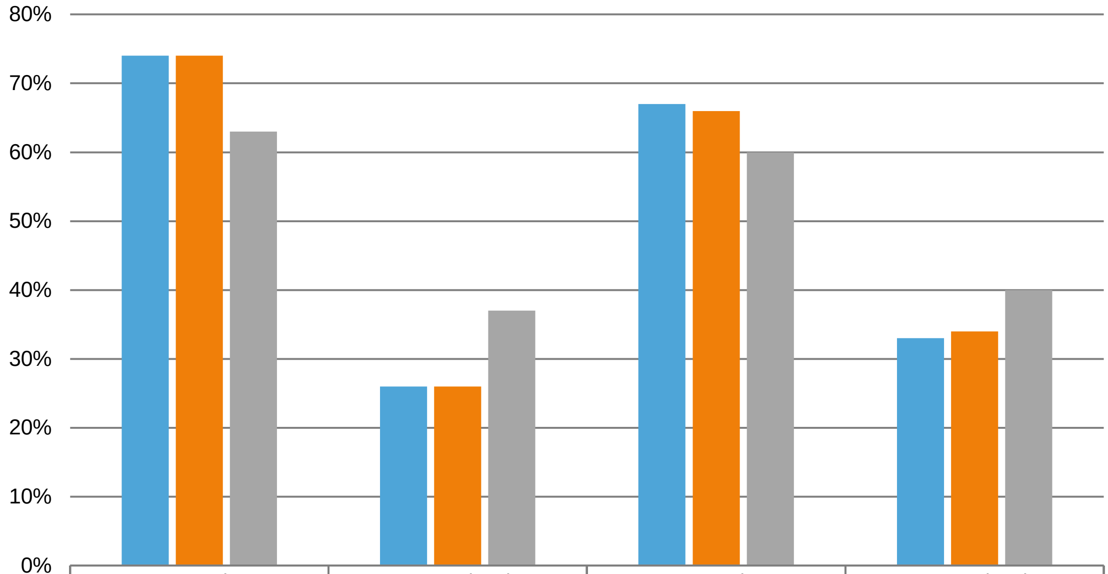
3.3.1 All Crashes by Travel Purpose

Figure 3.3 shows the proportions crashes in the commuting and recreational crash periods, for vehicle crashes and motorcycle crashes. The analysis shows that:

- For crashes involving vehicles only (vehicle crashes), more crashes occurred during the commuting period.
- For crashes involving motorcycles (motorcycle crashes), more crashes occurred during the commuting period.

A higher proportion of motorcycle crashes occurred in the recreational period compared to vehicle crashes in the recreation period.

Figure 3.3: Vehicle and motorcycle crashes in commuting and recreational periods by jurisdiction



	Vehicle crashes – Commuting	Vehicle crashes – Recreational	Motorcycle crashes – Commuting	Motorcycle crashes – Recreational
Queensland	74%	26%	67%	33%
South Australia	74%	26%	66%	34%
New Zealand	63%	37%	60%	40%

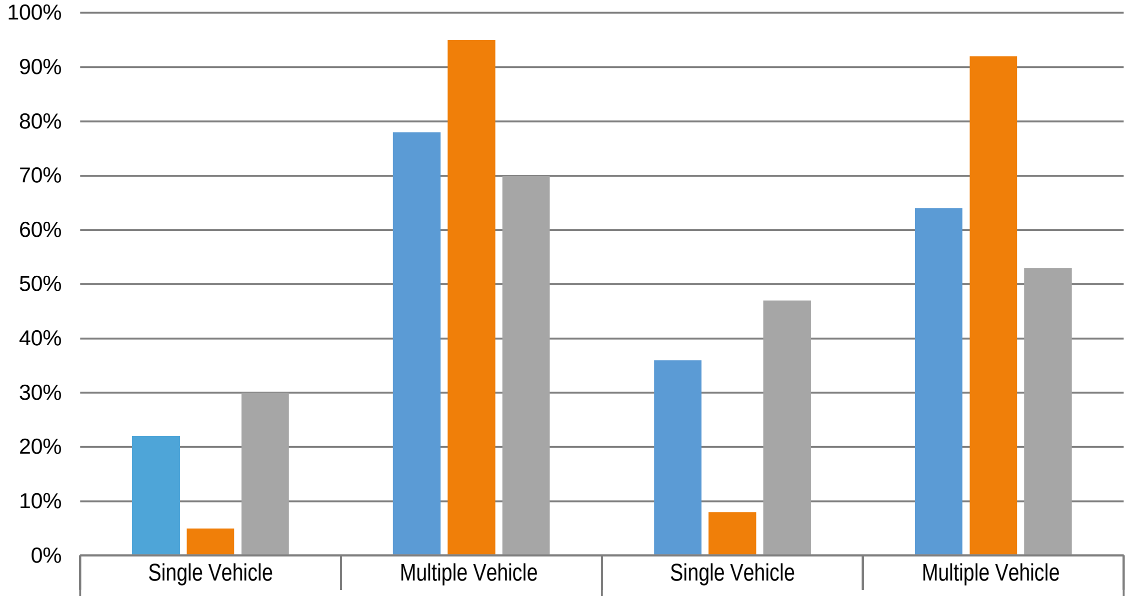
Note: Crashes are distributed by the number of vehicle or motorcycle crashes at intersections in each jurisdiction. The vehicle or motorcycle crashes shown for each jurisdiction in total equal 100%.

3.3.2 Crashes Involving Vehicles only by Travel Purpose

Figure 3.4 shows the proportion of single or multiple vehicle crashes in the commuting and recreational crash periods, for vehicle crashes. The analysis shows that:

- During commuting periods:
  - there were more multiple vehicle crashes than single vehicle crashes
  - most crashes involved multiple vehicles in South Australia.
- During recreational periods:
  - there were more multiple vehicle crashes than single vehicle crashes
  - most crashes in South Australia involved multiple vehicles.
- The proportion of single vehicle, vehicle crashes during the recreational period was higher than the proportion in the commuting period.

Figure 3.4: Vehicle crashes by commuting/recreational period and single/multiple vehicle crashes



	Commuting (vehicle crashes)		Recreational (vehicle crashes)	
	Single Vehicle	Multiple Vehicle	Single Vehicle	Multiple Vehicle
Queensland	22%	78%	36%	64%
South Australia	5%	95%	8%	92%
New Zealand	30%	70%	47%	53%

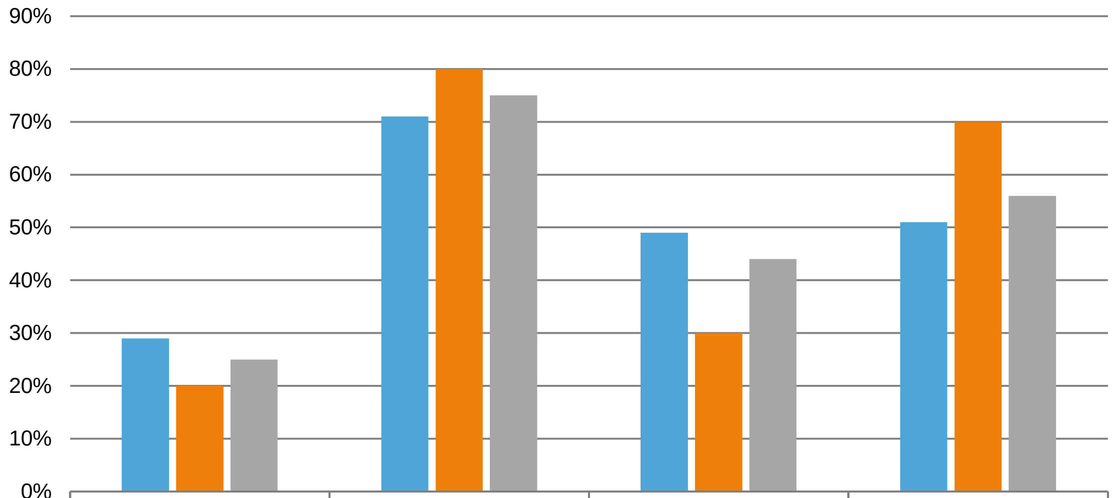
Note: Crashes are distributed by the number of vehicle or motorcycle crashes at intersections in each jurisdiction. The vehicle or motorcycle crashes shown for each jurisdiction in total equal 100%.

3.3.3 Crashes Involving Motorcycles by Travel Purpose

Figure 3.5 shows the proportion of single or multiple vehicle crashes in the commuting and recreational crash periods, for motorcycle crashes. The analysis shows that:

- During commuting and recreational periods there were more multiple vehicle, motorcycle crashes than single vehicle, motorcycle only crashes.
- A higher proportion of multiple vehicle, motorcycle crashes occurred during the commuting period compared to the recreational period.
- The proportion of single vehicle, motorcycle crashes during the recreational period was higher than the proportion in the commuting period.

Figure 3.5: Motorcycle crashes by commuting/recreational period and single/multiple vehicle crashes



	Commuting (motorcycle crashes)		Recreational (motorcycle crashes)	
	Single Vehicle	Multiple Vehicle	Single Vehicle	Multiple Vehicle
Queensland	29%	71%	49%	51%
South Australia	20%	80%	30%	70%
New Zealand	25%	75%	44%	56%

Note: Crashes are distributed by the number of vehicle or motorcycle crashes at intersections in each jurisdiction. The vehicle or motorcycle crashes shown for each jurisdiction in total equal 100%.

3.3.4 Vehicle and Motorcycle Crash Comparison by Travel Purpose

When comparing vehicle and motorcycle crashes by crash period, the analysis shows that:

- A higher proportion of motorcycle crashes (single and multiple) (Figure 3.5) occurred in the recreational period compared to vehicle crashes (single and multiple) (Figure 3.4).
- A higher proportion of single vehicle, motorcycle only, crashes occurred in both the commuting and recreational period (Figure 3.5) compared to single vehicle, vehicle crashes (Figure 3.4).

3.4 Relationship between Road Geometry, Intersections and Crashes

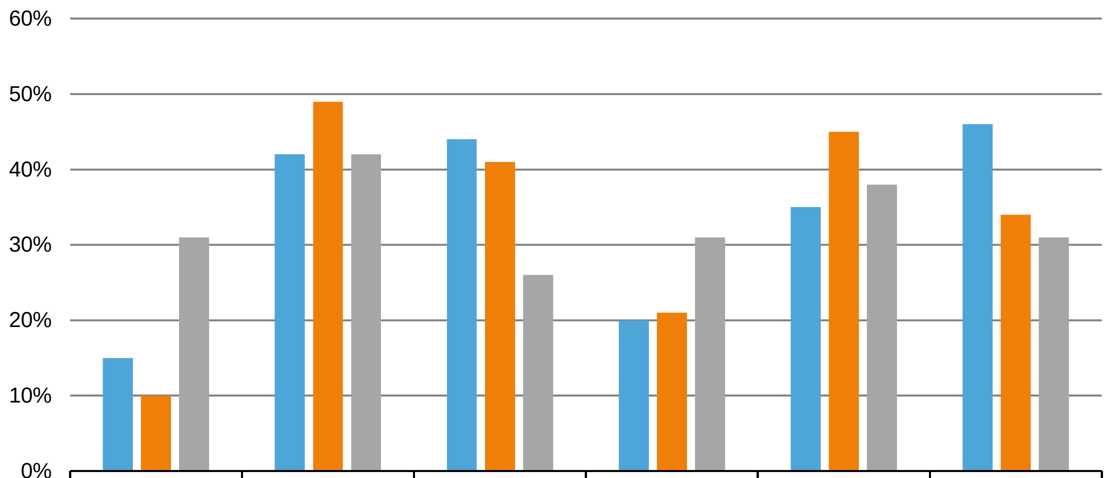
3.4.1 All Crashes by Road Feature

Figure 3.6 shows the proportion of all crashes, by road feature (road geometry and intersections). The analysis shows that:

- For vehicle crashes:
  - a majority of crashes occurred on a straight or at an intersection
  - the crashes on a straight or at an intersection were proportionate (excluding NZ)
  - in NZ a higher proportion of crashes occurred on curves.
- For motorcycle crashes:
  - a majority of crashes occurred on a straight or at an intersection (excluding NZ where the crashes were similar across all road features)
  - a higher proportion of crashes occurred on a straight (excluding NZ).

The proportion of motorcycle crashes on curves, is significantly higher than vehicle crashes on curves.

Figure 3.6: Comparison of vehicle and motorcycle crashes by road feature



	Vehicles			Motorcycles		
	Curve	Straight	Intersection	Curve	Straight	Intersection
Queensland	15%	42%	44%	20%	35%	46%
South Australia	10%	49%	41%	21%	45%	34%
New Zealand	31%	42%	26%	31%	38%	31%

Note: Crashes are distributed by the number of vehicle or motorcycle crashes at each road feature in each jurisdiction. The vehicle or motorcycle crashes shown for each jurisdiction in total equal 100%.

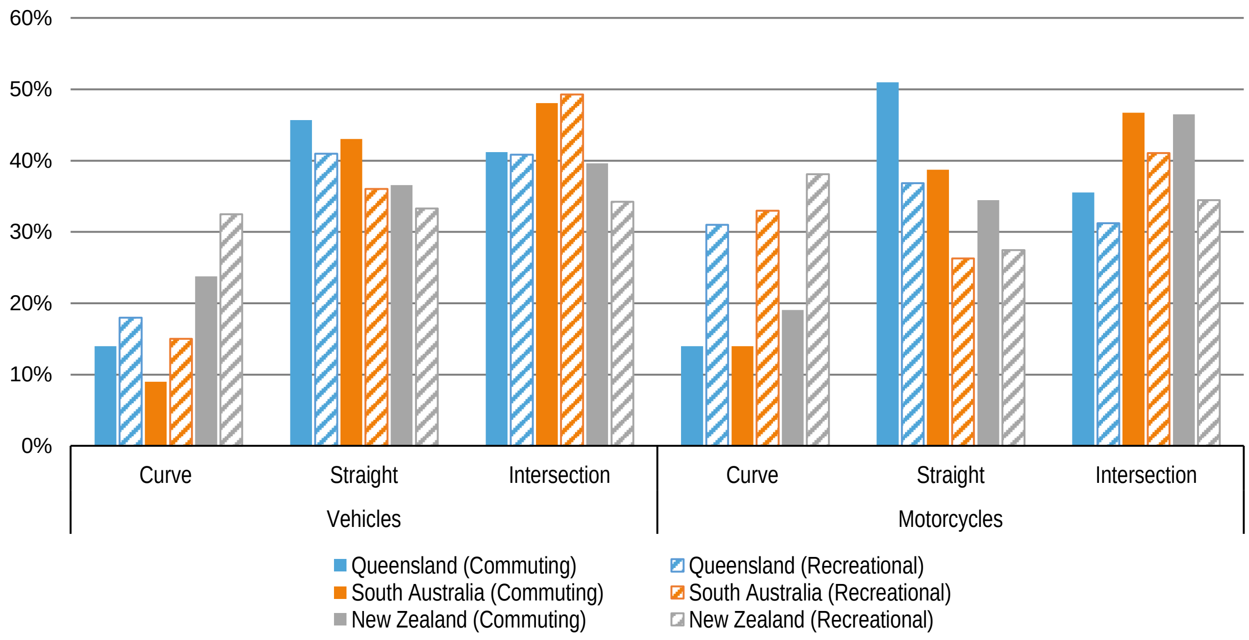
3.4.2 All by Road Feature and Travel Purpose

Figure 3.7 shows the proportion of all crashes, by road feature (road geometry and intersections), in the commuting and recreational crash periods. The analysis shows that:

- For vehicle crashes:
  - a majority of crashes during the commuting period occurred at intersections with the exception of QLD where there were slightly more crashes on a straight
  - a majority of crashes during the recreational period occurred at intersections in SA however the majority of crashes in QLD and NZ were similar on straights and intersections
  - the distribution of crashes on straights and intersections was similar for each crash period
  - a higher proportion of crashes on curves occurred during the recreational period.
- For motorcycle crashes:
  - a majority of crashes during the commuting period occurred at intersections with the exception of QLD where they tended to be on a straight
  - a majority of crashes during the recreational period occurred on a straight in QLD, at intersections in SA and on a curve in NZ
  - a higher proportion of motorcycle crashes occurred on curves during the recreational period
  - a higher proportion of motorcycle crashes occurred on straights and intersections during the commuting period.

The proportion of motorcycle crashes on curves, during the recreational period, is significantly higher than vehicle crashes.

Figure 3.7: Comparison of vehicle and motorcycle crashes by road feature and crash period



Note: Crashes are distributed by the number of vehicle or motorcycle crashes in each jurisdiction, in each crash period. The crashes shown for each crash period each jurisdiction, in total equal 100%.

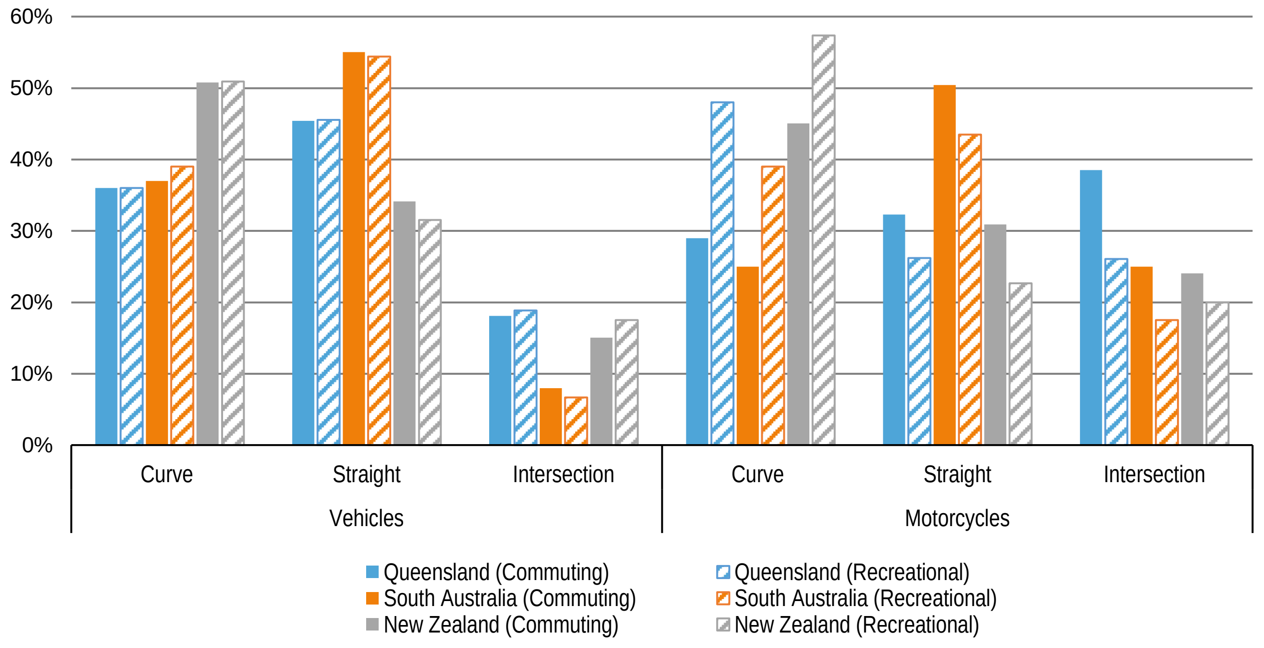
3.4.3 Single Vehicle Crashes by Road Feature and Travel Purpose

Figure 3.8 shows the proportion of all single vehicle, vehicle crashes and motorcycle crashes, by road feature (road geometry and intersections), in the commuting and recreational crash periods. The analysis shows that:

- For single vehicle, vehicle crashes:
  - the distribution of crashes for each road feature was similar for each crash period
  - a majority of crashes in each crash period occurred on a straight (excluding New Zealand), followed by crashes on curves
  - the least amount of crashes for each crash period were at intersections
  - the proportion of crashes in the recreation and commuting period were similar for each road feature
- For single vehicle, motorcycle only crashes:
  - a majority of crashes occurred on curves in the recreational period, with the exception of SA which had slightly more crashes on straights then curves
  - a higher proportion of crashes occurred on curves in the recreation period compared to the commuting period
  - a higher proportion of crashes occurred on straights and intersections in the commuting period compared to the recreation period.

A higher proportion of single vehicle, motorcycle only crashes occurred at intersections compared to single vehicle, vehicle crashes.

Figure 3.8: Single vehicle and motorcycle-only crashes by road feature and crash period



Note: Crashes are distributed by the number of vehicle or motorcycle crashes in each jurisdiction, in each crash period. The crashes shown for each crash period each jurisdiction, in total equal 100%

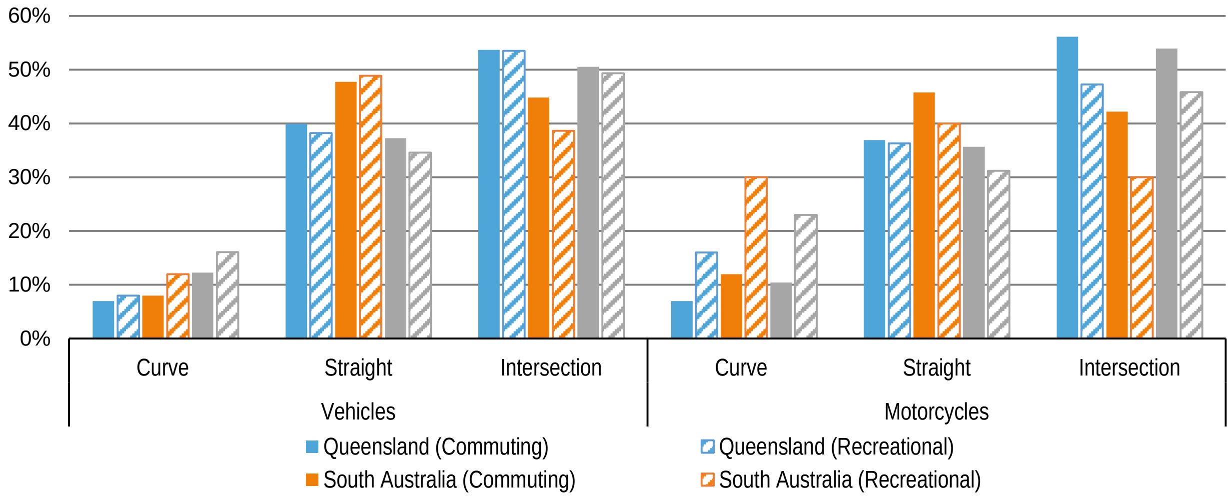
3.4.4 Multiple Vehicle Crashes by Road Feature and Travel Purpose

Figure 3.9 shows the proportion of all multiple vehicle, vehicle crashes and motorcycle crashes, by road feature (road geometry and intersections), in the commuting and recreational crash periods. The analysis shows that:

- For multiple vehicle, vehicle crashes:
  - the distribution of crashes for each road feature was similar for each crash period
  - a majority of crashes in each crash period occurred at intersections in QLD and NZ and on a straight in SA
  - the least amount of crashes for each crash period were on a curve.
- For multiple vehicle, motorcycle crashes:
  - a majority of crashes in the commuting period occurred at intersections in QLD and NZ and on a straight in SA
  - a majority of crashes in the recreation period occurred at intersections in QLD and NZ and on a straight in SA
  - during the commuting period a higher proportion of crashes occurred at intersections and on a straight compared to the recreational period
  - during the recreational period a higher proportion of crashes occurred on a curve compared to the commuting period.

A higher proportion of multiple vehicle, motorcycle crashes occurred on curves during the recreational period compared to multiple vehicle, vehicle crashes in the recreational period.

Figure 3.9: Multiple vehicle crashes by road feature and crash period



Note: Crashes are distributed by the number of vehicle or motorcycle crashes in each jurisdiction, in each crash period. The crashes shown for each crash period each jurisdiction, in total equal 100%.

3.4.5 Single and Multiple Vehicle, Motorcycle Crash Comparison by Road Feature

A comparison of single and multiple vehicle, motorcycle crashes by commuting or recreational period and road feature (curve, straight and intersection) shows that:

- the proportion of crashes on curves is higher for motorcycle only crashes, particularly in the recreational period
- the proportions of motorcycle only and multiple vehicle, motorcycle crashes on a straight are similar in the commuting period
- the proportion of motorcycle only, motorcycle crashes on a straight in the recreational period is lower than multiple vehicle, motorcycle crashes in the commuting period.

3.5 Mid-block Crashes

3.5.1 Mid-block Vehicle and Motorcycle Crashes by Horizontal Geometry

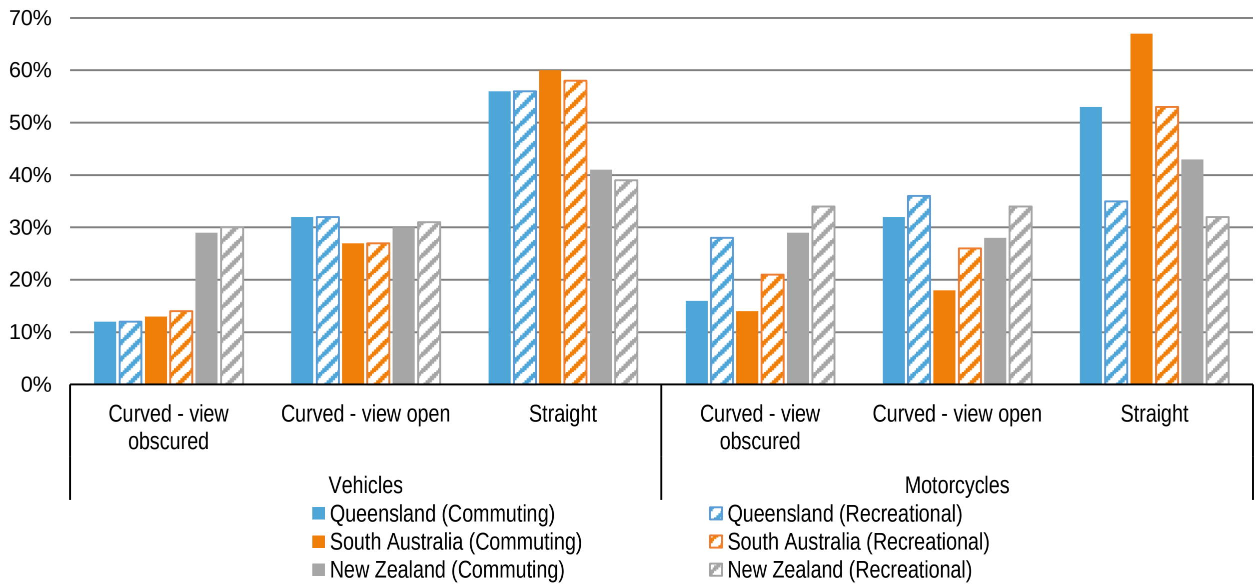
In New Zealand there was no differentiation between view obscured and view open, hence for comparative purposes, the New Zealand curve crash data has been halved between obscured and open curve.

Figure 3.10 shows the proportion of single vehicle, vehicle crashes and motorcycle crashes on the mid-block, by horizontal geometry, in the commuting and recreational crash periods. The analysis shows that:

- For single vehicle, vehicle crashes:
  - the distribution of crashes for each road feature was similar for each crash period
  - a majority of crashes in each crash period occurred on straights
  - more crashes occurred on curves with an open view compared to curves with a closed view in each crash period
- For single vehicle, motorcycle only crashes:
  - a majority of crashes in the commuting period occurred on a straight in QLD and SA and on a curve in NZ
  - a majority of crashes in the recreation period occurred on a curve in QLD and NZ and on a straight in SA
  - during the commuting period a higher proportion of crashes occurred on a straight compared to the recreational period
  - during the recreational period a higher proportion of crashes occurred on a curve compared to the commuting period
  - a higher proportion of crashes occurred on a curve with an open view in both crash periods (not including NZ, as view obscured or view open was not specified).

A higher proportion of single vehicle, motorcycle only crashes occurred on curves (namely curves with an obscured view) during the recreational period compared to multiple vehicle, vehicle crashes in the recreational period.

Figure 3.10: Single vehicle mid-block crashes by horizontal geometry and crash period



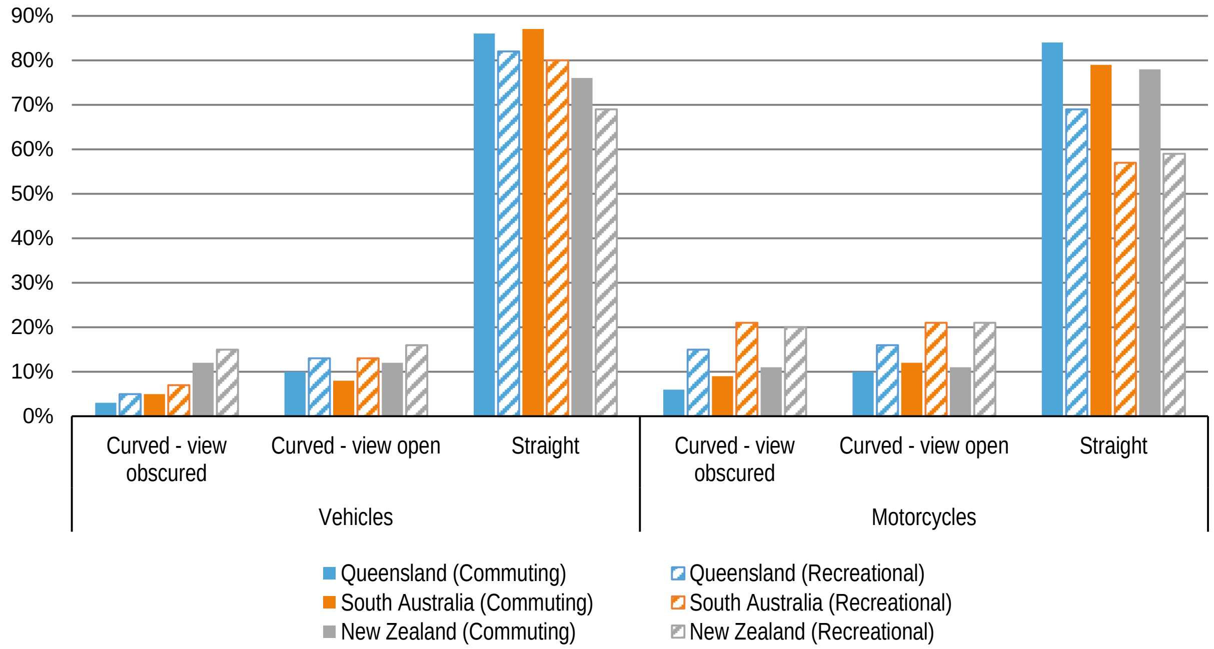
Note: Crashes are distributed by the number of vehicle or motorcycle crashes in each jurisdiction, in each crash period. The crashes shown for each crash period each jurisdiction, in total equal 100%.

Figure 3.11 shows the proportion of all multiple vehicle, vehicle crashes and motorcycle crashes on the mid-block, by horizontal geometry, in the commuting and recreational crash periods. The analysis shows that:

- For multiple vehicle, vehicle crashes:
  - the distribution of crashes for each road feature was similar for each crash period
  - almost all crashes in each crash period occurred on straights
  - more crashes occurred on curves with an open view compared to curves with a closed view in each crash period
- For multiple vehicle, motorcycle crashes:
  - on a straight a higher proportion of crashes occurred in the commuting period compared to the recreational period
  - a majority of crashes in each crash period occurred on a straight
  - a higher proportion of crashes (approximately double) occurred on curves during the recreational period compared to the commuting period
  - the proportion of crashes on curves with an open view is higher in the recreational period
  - the proportion of crashes that occurred on a curve with an open view or obscured view in the recreational period was similar (not including NZ, as view obscured or view open was not specified).

A higher proportion of multiple vehicle, motorcycle crashes occurred on curves (both view obscured and open view) compared to multiple vehicle, vehicle crashes during the recreational period.

Figure 3.11: Multiple vehicle mid-block crashes by horizontal geometry and crash period



Note: Crashes are distributed by the number of vehicle or motorcycle crashes in each jurisdiction, in each crash period. The crashes shown for each crash period each jurisdiction, in total equal 100%.

3.5.2 Mid-block Vehicle and Motorcycle Crashes by Vertical Geometry

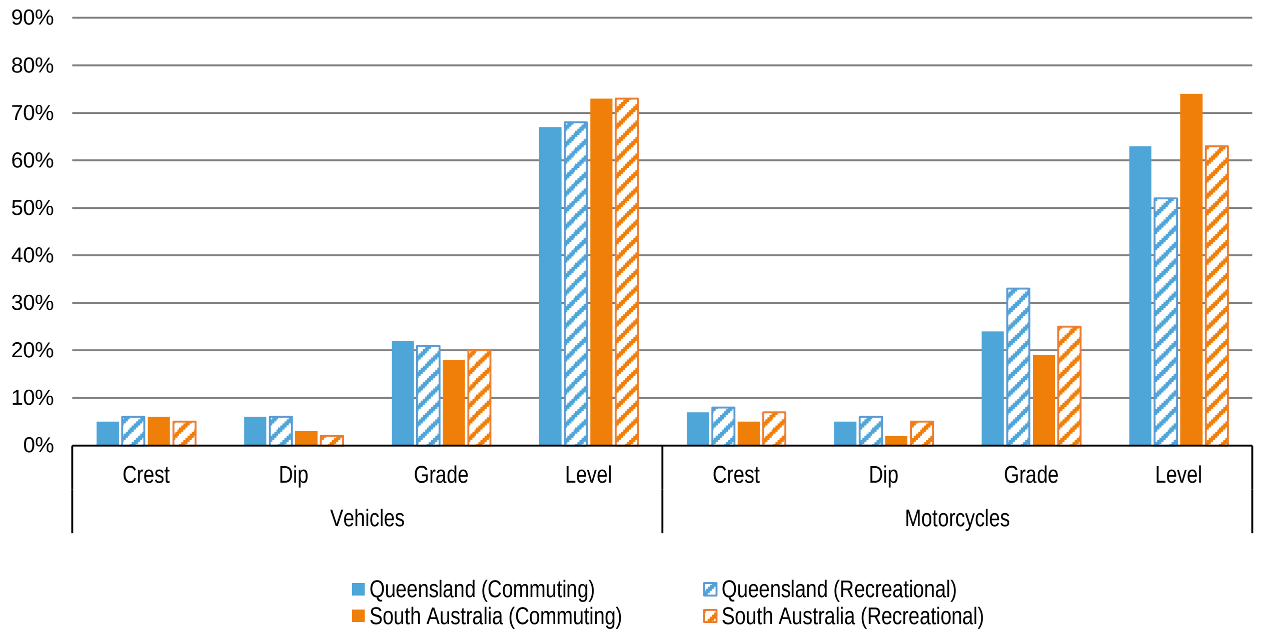
Mid-block crash analysis by vertical road geometry was conducted for Queensland and South Australian data only. The data from New Zealand did not include vertical road geometry crash information.

Figure 3.12 shows the proportion of single vehicle, vehicle crashes and motorcycle crashes on the mid-block, by vertical geometry, in the commuting and recreational crash periods. The analysis shows that:

- For single vehicle, vehicle crashes:
  - the distribution of crashes for each road feature was similar for each crash period
  - a majority of crashes in each crash period occurred on level ground, followed by crashes on a grade.
- For single vehicle, motorcycle only crashes:
  - the majority of crashes in each crash period occurred on level ground, followed by crashes on a grade
  - during the commuting period a higher proportion of crashes occurred on level ground compared to the recreational period
  - during the recreational period a higher proportion of crashes occurred on a grade compared to the commuting period
  - during the recreational period a slightly higher proportion of crashes occurred on crests and in dips compared to the commuting period.

A higher proportion of single vehicle, motorcycle only crashes occurred on a grade during the recreational period compared to that of single vehicle, vehicle crashes in the recreational period.

Figure 3.12: Single vehicle mid-block crashes by vertical geometry and crash period



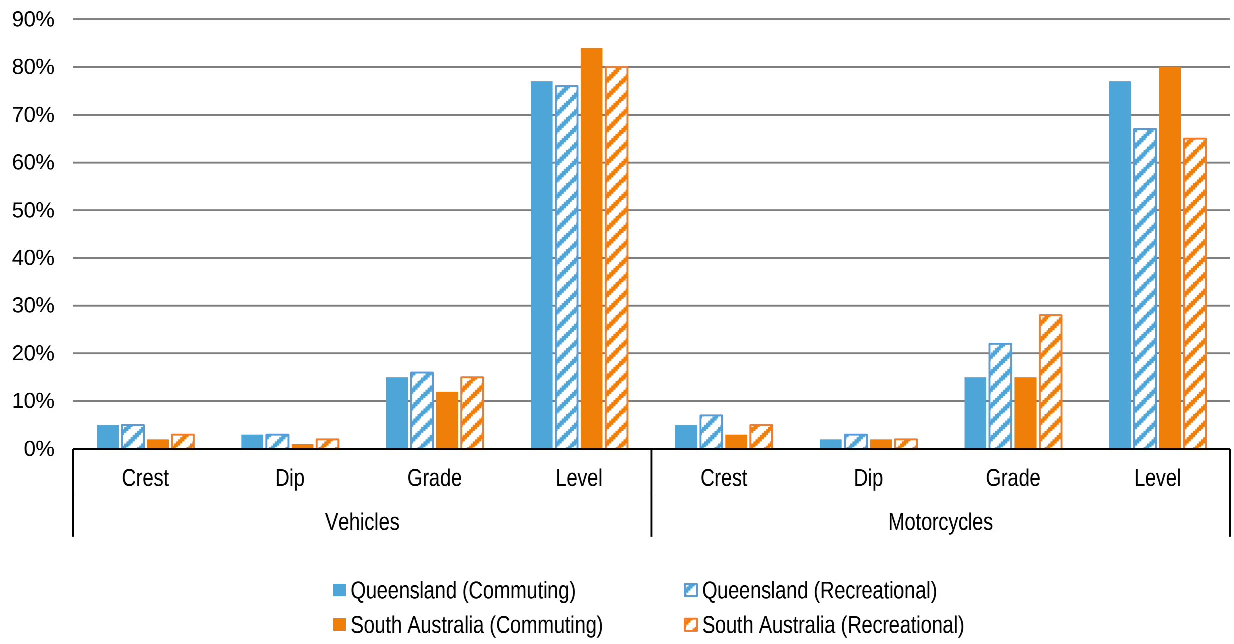
Note: Crashes are distributed by the number of vehicle or motorcycle crashes in each jurisdiction, in each crash period. The crashes shown for each crash period each jurisdiction, in total equal 100%.

Figure 3.13 shows the proportion of multiple vehicle, vehicle crashes and motorcycle crashes on the mid-block, by vertical geometry, in the commuting and recreational crash periods. The analysis shows that:

- For multiple vehicle, vehicle crashes:
  – the distribution of crashes for each road feature was similar for each crash period
  – a majority of crashes in each crash period occurred on level ground, followed by crashes on a grade.
- For multiple vehicle crashes involving a motorcycle:
  – the majority of crashes in each crash period occurred on level ground, followed by crashes on a grade
  – during the commuting period a higher proportion of crashes occurred on level ground compared to the recreational period
  – during the recreational period a higher proportion of crashes occurred on a grade compared to the commuting period
  – during the recreational period a slightly higher proportion of crashes occurred on crests and in dips compared to the commuting period.

A higher proportion of multiple vehicle, motorcycle crashes occurred on a grade during the recreational period compared to that of single vehicle, vehicle crashes in the recreational period.

Figure 3.13: Multiple vehicle mid-block crashes by vertical geometry and crash period



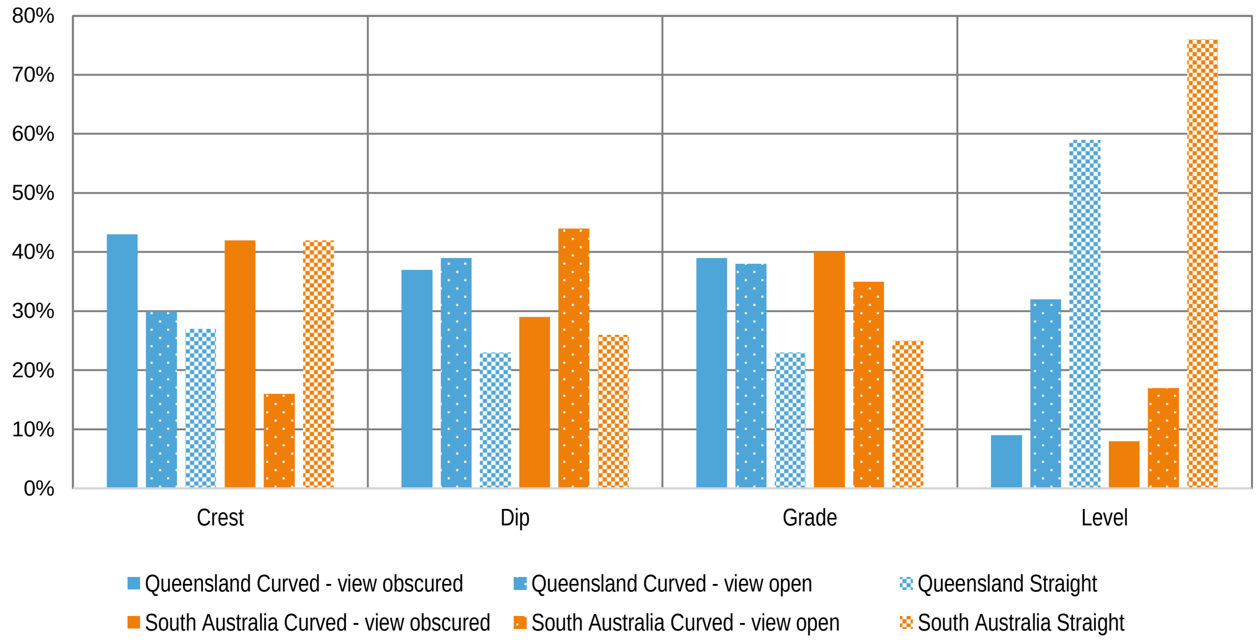
Note: Crashes are distributed by the number of vehicle or motorcycle crashes in each jurisdiction, in each crash period. The crashes shown for each crash period in each jurisdiction, in total equal 100%.

3.5.3 Mid-block Motorcycle Crashes by Horizontal and Vertical Geometry

Figure 3.14 shows the proportion of single vehicle, motorcycle only crashes on the mid-block, by horizontal geometry and vertical geometry, in the commuting and recreational crash periods. The analysis shows that:

- On a crest, the majority of crashes occurred on a curve, namely a view obscured curve.
- In a dip, the majority of crashes occurred on a curve, namely a view open curve.
- On a grade, the majority of crashes occurred on a curve, these were almost equally distributed between view obscured and open view curves.
- On level ground, the majority of crashes occurred on a straight, with a considerable proportion being on an open view curve in QLD.

Figure 3.14: Single motorcycle crashes by horizontal and vertical geometry type

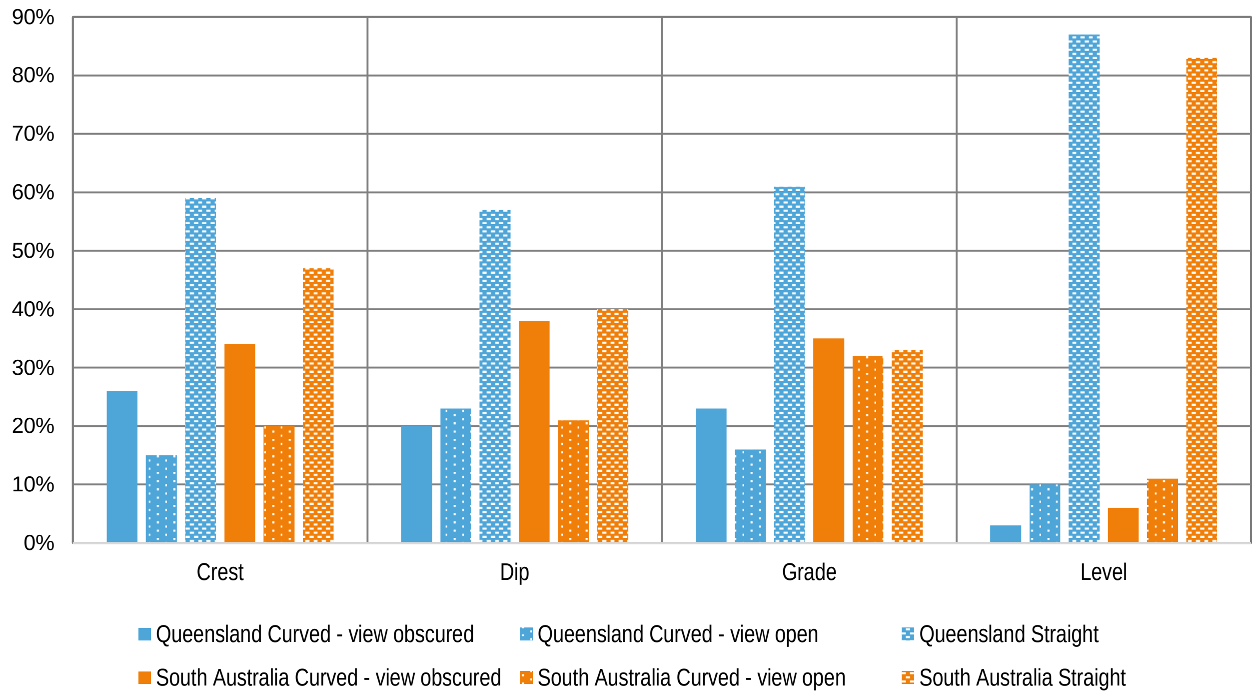


Note: Crashes are distributed by the number of motorcycle crashes for each horizontal and vertical geometry combination in each jurisdiction, The crashes shown for each horizontal and vertical geometry combination in each jurisdiction, in total equal 100%.

Figure 3.15 shows the proportion of multiple vehicle, motorcycle crashes on the mid-block, by horizontal geometry and vertical geometry, in the commuting and recreational crash periods. The analysis shows that:

- On a crest, slightly more crashes occurred on a straight in SA.
- In a dip, the majority of crashes occurred on a straight.
- On a grade, the majority of crashes occurred on a curve, these were almost equally distributed between view obscured and open view curves.
- On level ground, the majority of crashes occurred on a straight, with a considerable proportion being on an open view curve in QLD.

Figure 3.15: Multiple vehicle crashes involving a motorcycle by horizontal and vertical geometry type



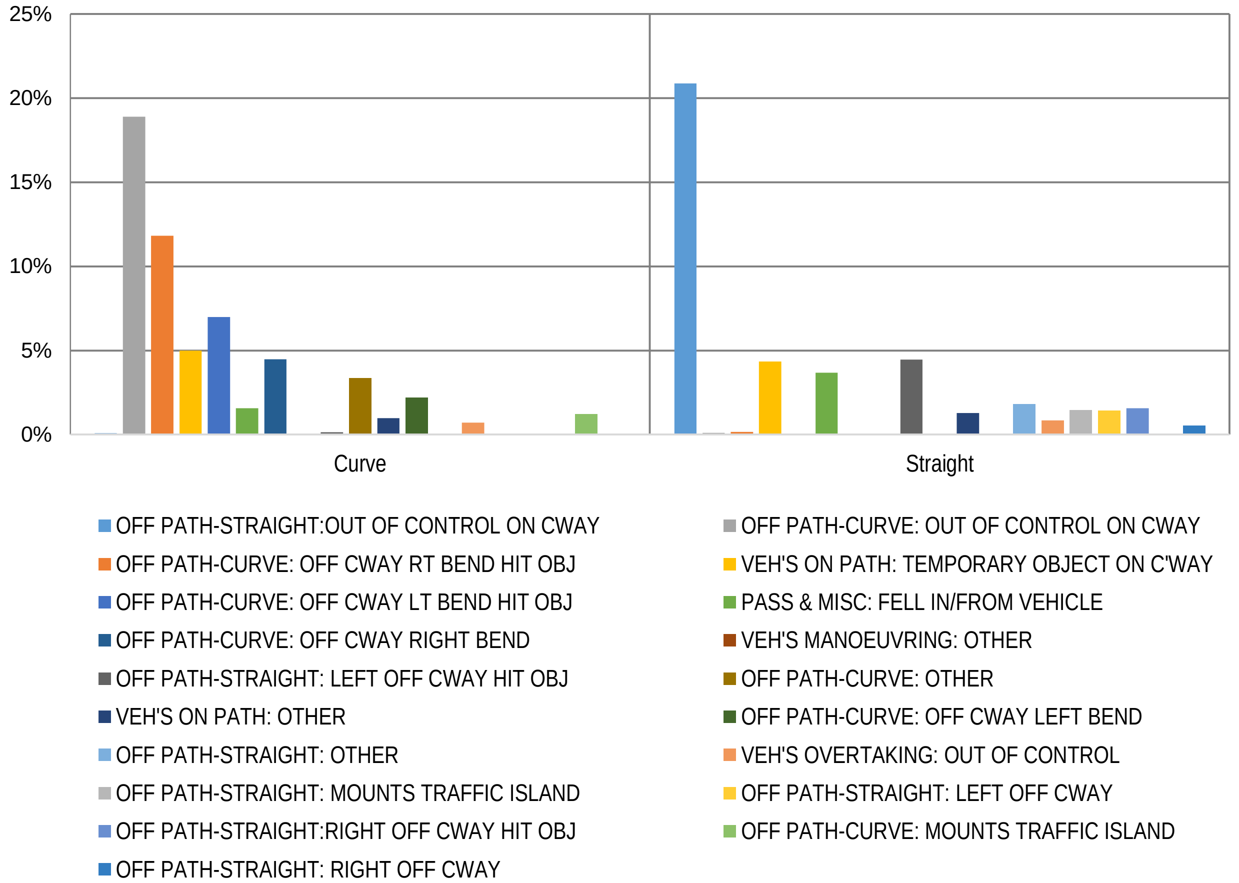
Note: crashes are distributed by the number of motorcycle crashes for each horizontal and vertical geometry combination in each jurisdiction. The crashes shown for each horizontal and vertical geometry combination in each jurisdiction, in total equal 100%.

3.5.4 Mid-block Crashes by Crash Type (Crash Nature, DCA or Movement Code)

Figure 3.16 shows the proportion of single vehicle, motorcycle only crashes on the mid-block in Queensland, by horizontal geometry. The analysis shows that:

- On the mid-block 57% of motorcycle only crashes occurred on curves and 43% on a straight.
- On curves, the majority of crashes were:
  - off path-curve: out of control on carriageway
  - off path-curve: off carriageway right bend hit object
  - off path-curve: off carriageway left bend hit object
- On straights, the majority of crashes were:
  - off path-straight: out of control on carriageway
  - off path-straight: left off carriageway hit object
  - vehicles on path: temporary object on carriageway.

Figure 3.16: Queensland single vehicle, motorcycle-only crashes on midblocks

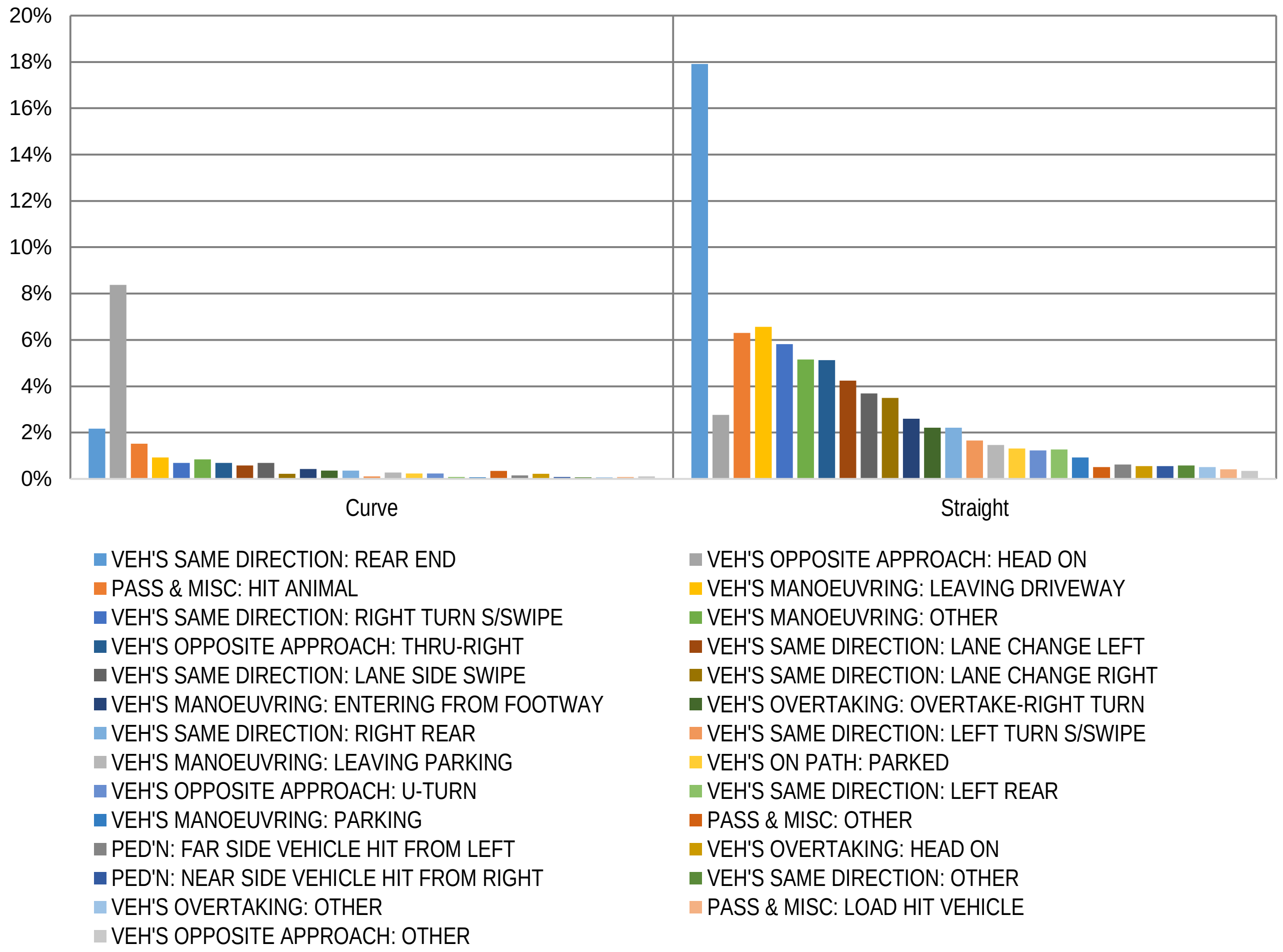


Note: crashes are distributed by the number of mid-block, single vehicle motorcycle only crashes in each jurisdiction. The crashes shown for curve and straight in total equal 100%.

Figure 3.17 shows the proportion of multiple vehicle, motorcycle crashes on the mid-block in Queensland, by horizontal geometry. The analysis shows that:

- On the mid-block 80% of multiple vehicle, motorcycle crashes occurred on a straight and 20% on a curve.
- On curves, the most frequent crash types were:
  - vehicles opposite approach: head-on
  - vehicles same direction: rear end
  - passengers and miscellaneous: hit animal.
- On straights, the most frequent crash types were:
  - vehicles same direction: rear end
  - vehicle manoeuvring: leaving driveway
  - passengers and miscellaneous: hit animal.

Figure 3.17: Queensland multiple vehicle crashes involving a motorcycle on midblocks

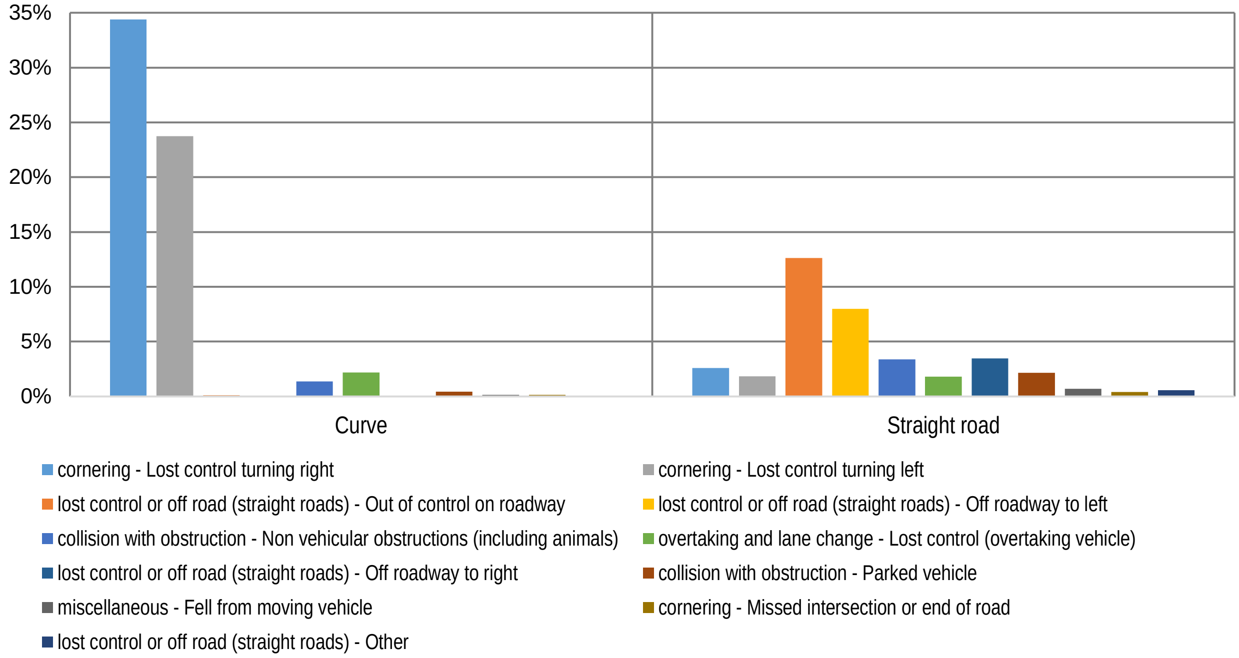


Note: Crashes are distributed by the number of mid-block, single vehicle and motorcycle only crashes. The crashes shown for curve and straight in total equal 100%.

Figure 3.18 shows the proportion of single vehicle, motorcycle only crashes on the mid-block in New Zealand, by horizontal geometry. The analysis shows that:

- On the mid-block 63% of motorcycle only crashes occurred on curves and 37% on a straight.
- On curves, the most frequent crash types were:
  - cornering – lost control turning right
  - cornering – lost control turning left.
- On straights, the most frequent crash types were:
  - lost control or off road (straight roads) – out of control on roadway
  - lost control or off road (straight roads) – off roadway to left.

Figure 3.18: New Zealand single vehicle, motorcycle-only crashes on midblocks

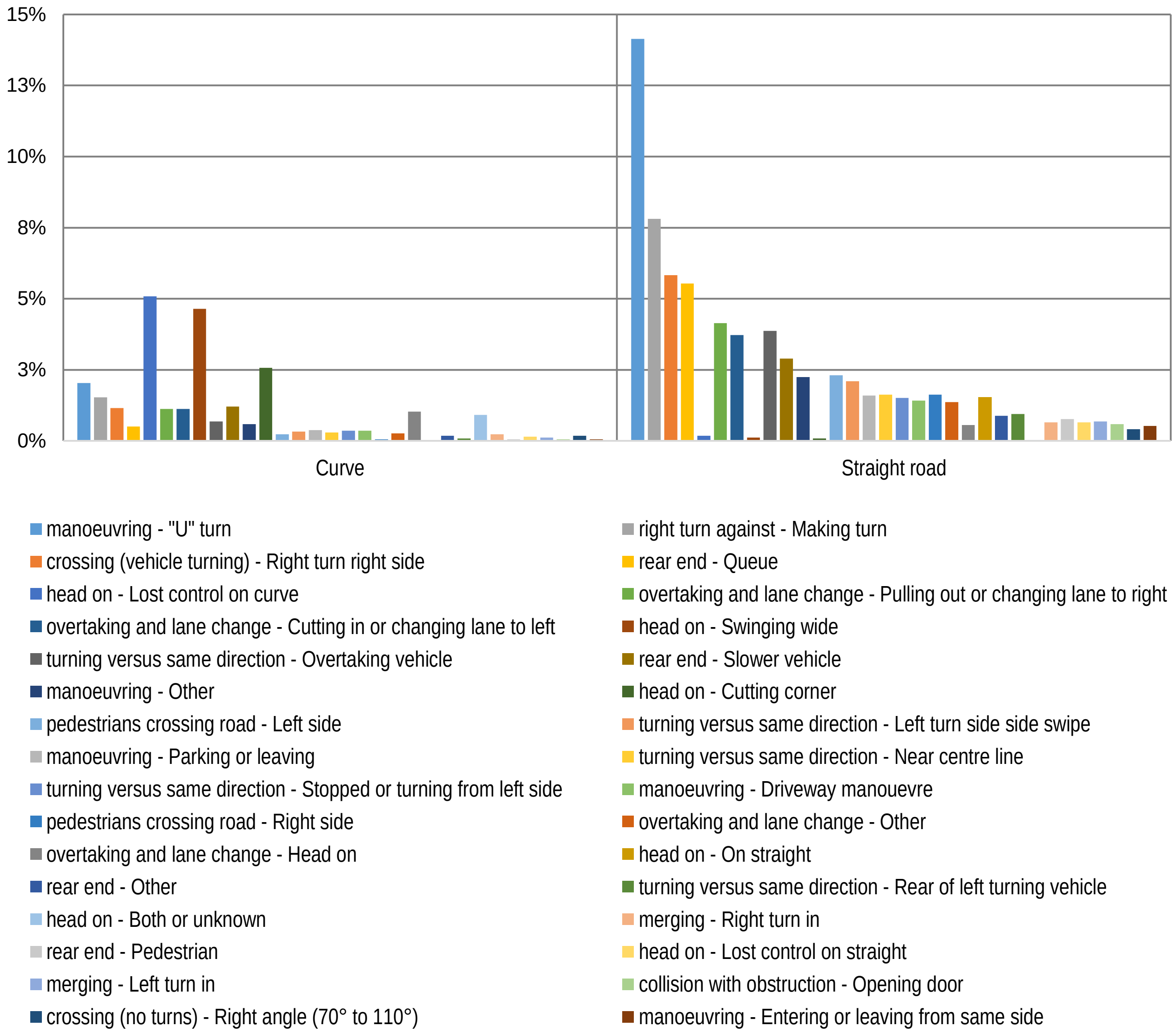


Note: Crashes are distributed by the number of mid-block, single vehicle and motorcycle only crashes. The crashes shown for curve and straight in total equal 100%.

Figure 3.19 shows the proportion of multiple vehicle, motorcycle crashes on the mid-block in New Zealand, by horizontal geometry. The analysis shows that:

- On the mid-block 72% of multiple vehicle, motorcycle crashes occurred on a straight and 28% on a straight.
- On curves, the most frequent crash types were:
  - head on – lost control on curve
  - head on – swinging wide.
- On straights, the most frequent crash types were:
  - manoeuvring – U turn
  - right turn against – making turn
  - crossing (vehicle turning) – right turn right side
  - rear end – queue.

Figure 3.19: New Zealand multiple vehicle crashes involving a motorcycle on midblocks



Note: Crashes are distributed by the number of mid-block, single vehicle and motorcycle only crashes. The crashes shown for curve and straight in total equal 100%.

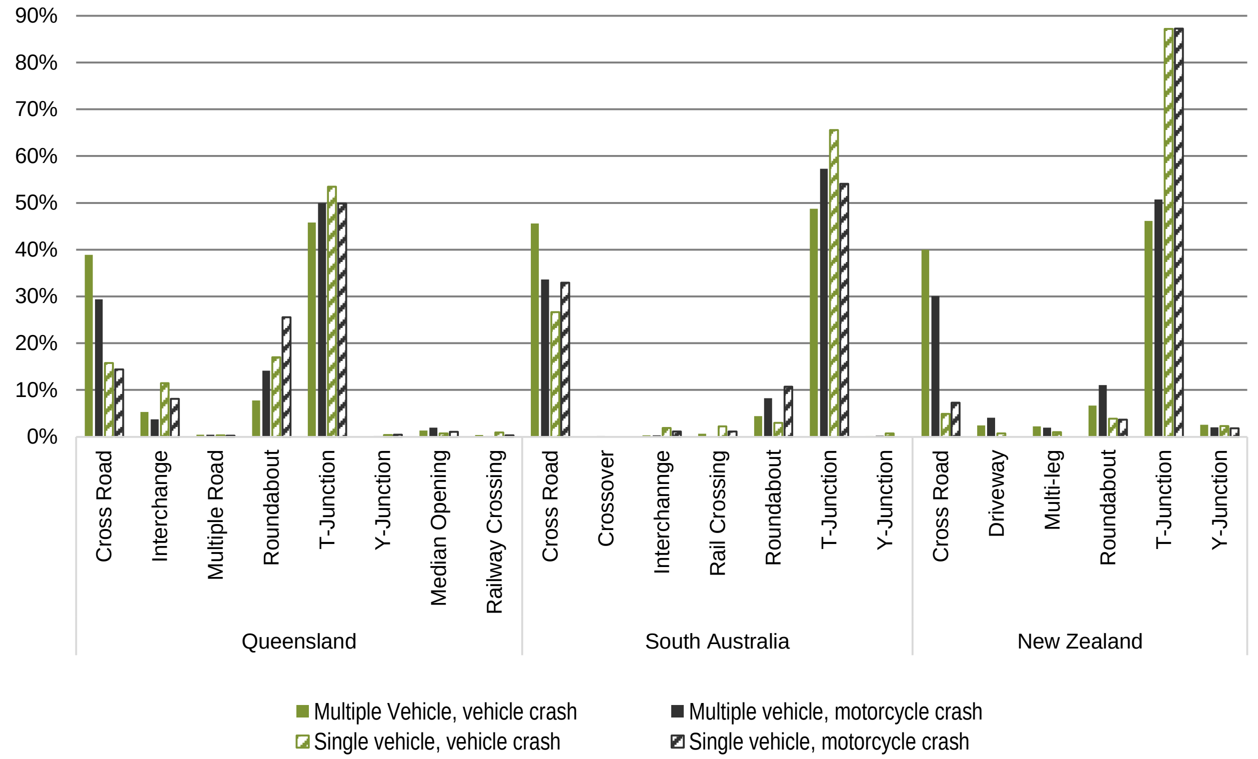
3.6 Intersection Crashes

3.6.1 All Crashes by Intersection Type

Figure 3.20 shows vehicle and motorcycle crashes at intersections, by intersection type. The analysis shows that:

- The majority vehicle crashes and motorcycle crashes occurred at a T-junction, followed by crossroads, then roundabouts for all jurisdictions.
- The proportion of single and multiple vehicle, vehicle crashes and motorcycle crashes was similar.
- New Zealand had a significantly higher proportion of T-junction crashes for both single vehicle and single motorcycle crashes compared to other jurisdictions.

Figure 3.20: All intersection crashes by single or multiple vehicle or motorcycle crash



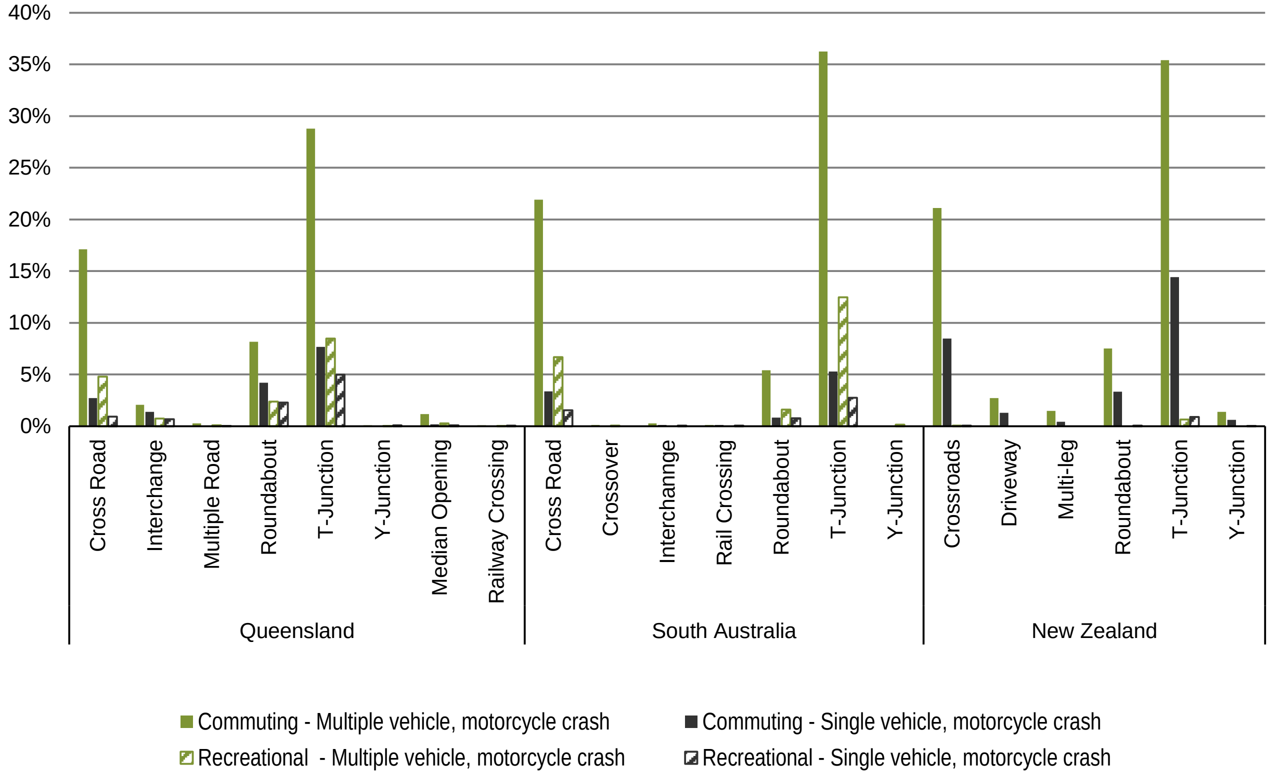
Note: All intersection crashes are distributed by the categories shown in the legend, each legend category, for each jurisdiction totals 100%.

3.6.2 Motorcycle Crashes by Intersection Type and Travel Purpose

Figure 3.21 shows the distribution of motorcycle crashes at intersections, by intersection type, crash period and multiple or single vehicle crash. The analysis shows that:

- The majority of intersection crashes occurred at a T-junction (50–60%), followed by crossroads (30–35%) and roundabouts (10–20%) in each jurisdiction.
- The majority of crashes where multiple vehicle, crashes involving a motorcycle, during the commuting period where at a T-junction, followed by crossroads.
- The highest proportion of crashes in the recreational period occurred at a T-junction.
- The highest proportion of single vehicle, motorcycle only crashes occurred in the commuting period at a T-junction.

Figure 3.21: Motorcycle intersection crashes by intersection type and crash period



Note: Crashes are distributed by the number of motorcycle crashes at intersections in each jurisdiction. The crashes shown for each jurisdiction in total equal 100%.

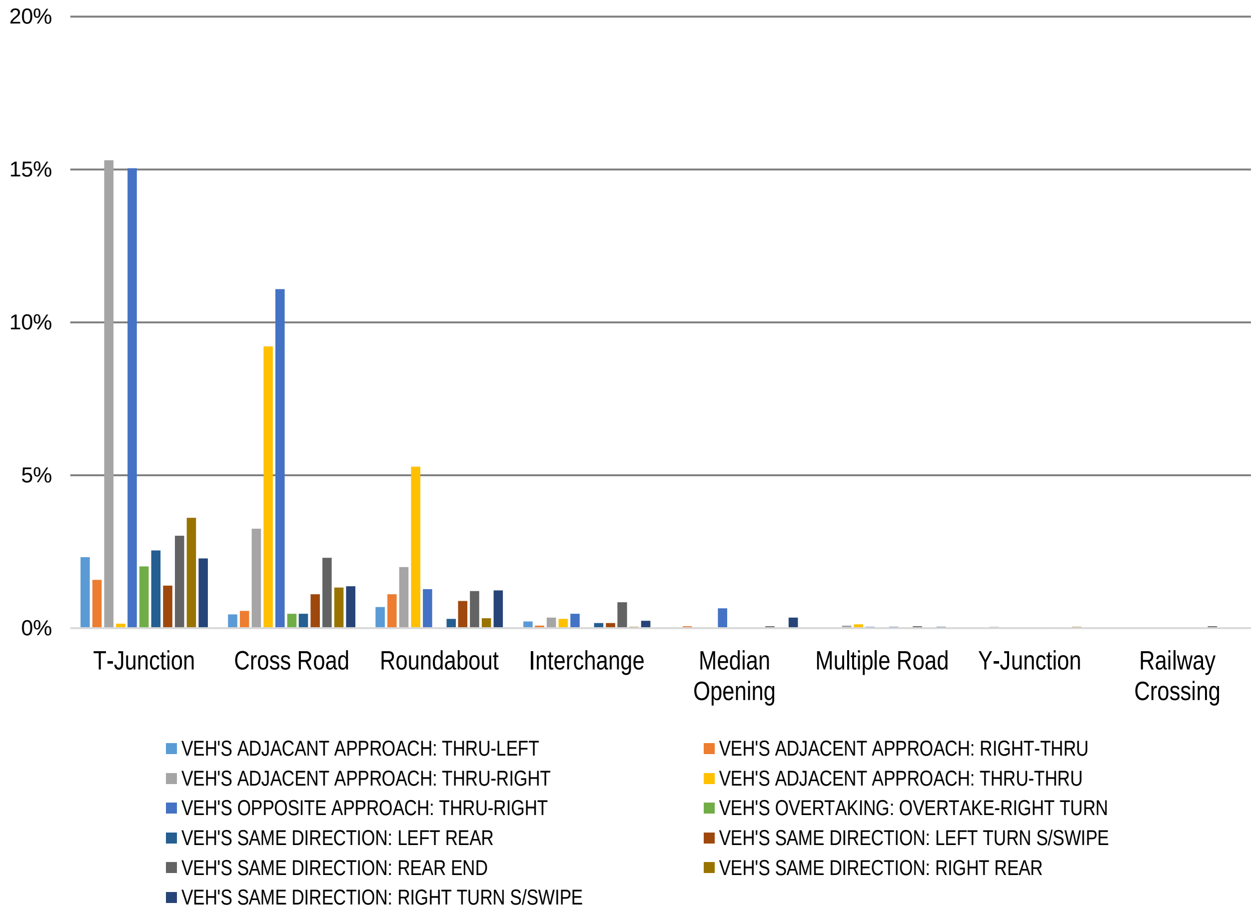
3.6.3 Intersection Motorcycle Crashes by Crash Code

All intersection crash codes were converted to the Queensland crash DCA description so as the intersection crash types could be compared for the three jurisdictions.

Figure 3.22 shows the distribution of motorcycle crashes at intersections in Queensland, by intersection type and crash description. The analysis shows that the majority of crashes were:

- The majority of crashes (97%) occurred at a T-junction, crossroad or roundabout. These crashes included the following:
  - vehicles adjacent approach (thru-right) and opposite approach (thru-right) at T-junctions
  - vehicles adjacent approach (thru-thru) and opposite approach (thru-right) at crossroads
  - vehicles adjacent approach (thru-thru) at roundabouts.

Figure 3.22: Queensland motorcycle intersection crashes by intersection type and crash description

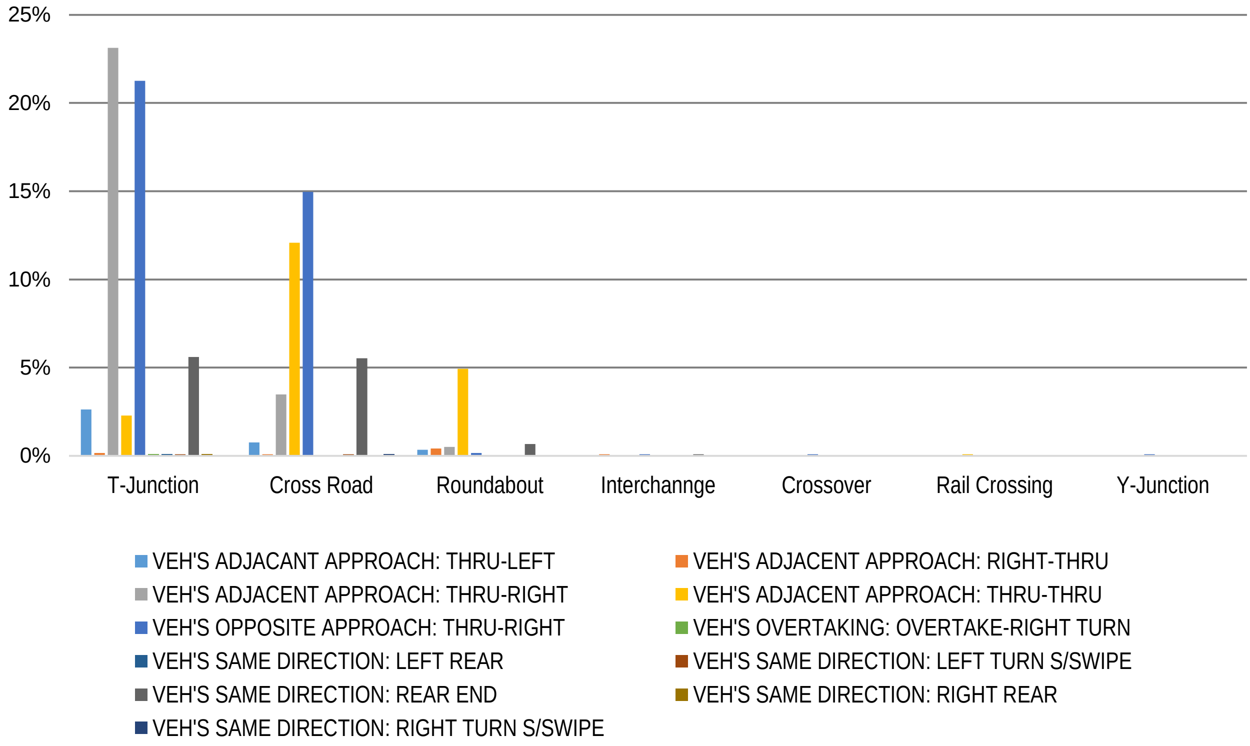


Note: Crashes are distributed by the number of motorcycle crashes at intersections. The crashes shown in total equal 100%.

Figure 3.23 shows the distribution of motorcycle crashes at intersections in South Australia, by intersection type and crash description. The analysis shows that the majority of crashes were:

- The majority of crashes (99%) occurred at a T-junction, crossroad or roundabout. These crashes included the following:
  - vehicles adjacent approach (thru-right) and opposite approach (thru-right) at T-junctions
  - vehicles adjacent approach (thru-thru) and opposite approach (thru-right) at crossroads
  - vehicles adjacent approach (thru-thru) at roundabouts.

Figure 3.23: South Australian motorcycle intersection crashes by intersection type and crash description

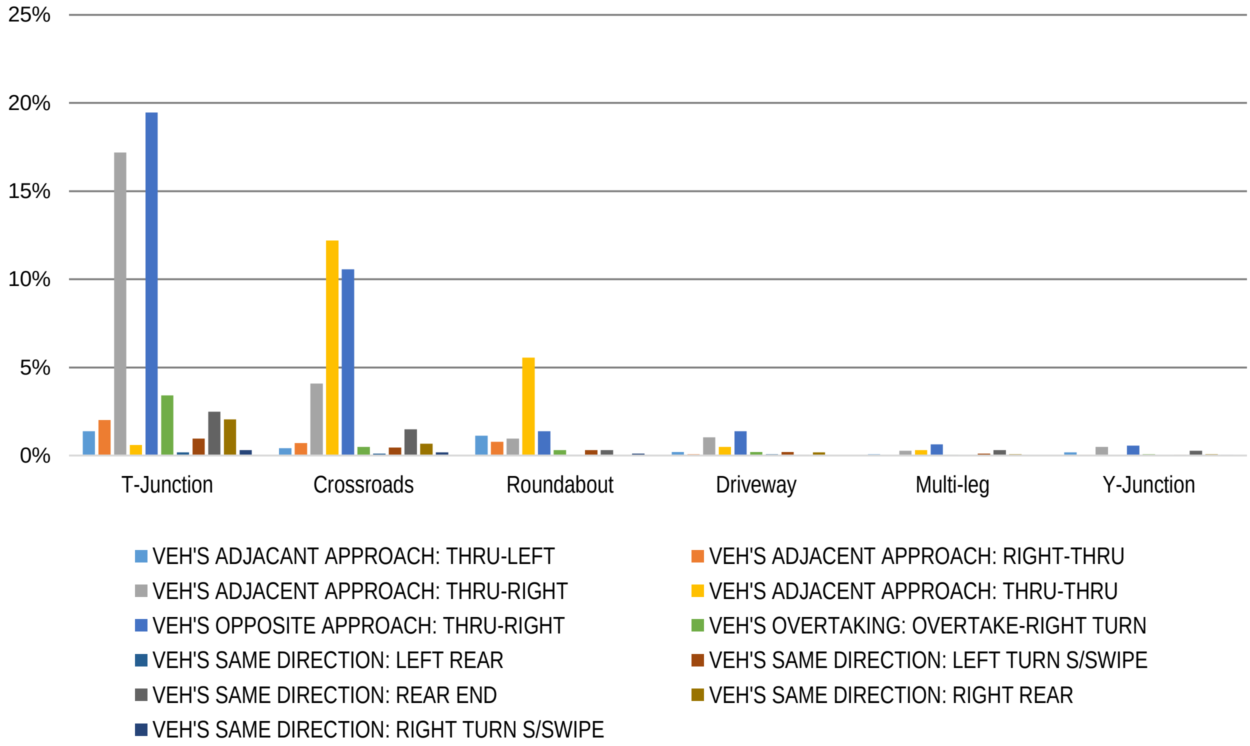


Note: Crashes are distributed by the number of motorcycle crashes at intersections. The crashes shown in total equal 100%.

Figure 3.24 shows the distribution of motorcycle crashes at intersections in New Zealand, by intersection type and crash description. The analysis shows that the majority of crashes were:

- The majority of crashes (92%) occurred at a T-junction, crossroad or roundabout. These crashes included the following:
  - vehicles adjacent approach (thru-right) and opposite approach (thru-right) at T-junctions
  - vehicles adjacent approach (thru-thru) and opposite approach (thru-right) at crossroads
  - vehicles adjacent approach (thru-thru) at roundabouts.

Figure 3.24: New Zealand motorcycle intersection crashes by intersection type and crash description



Note: Crashes are distributed by the number of motorcycle crashes at intersections. The crashes shown in total equal 100%.

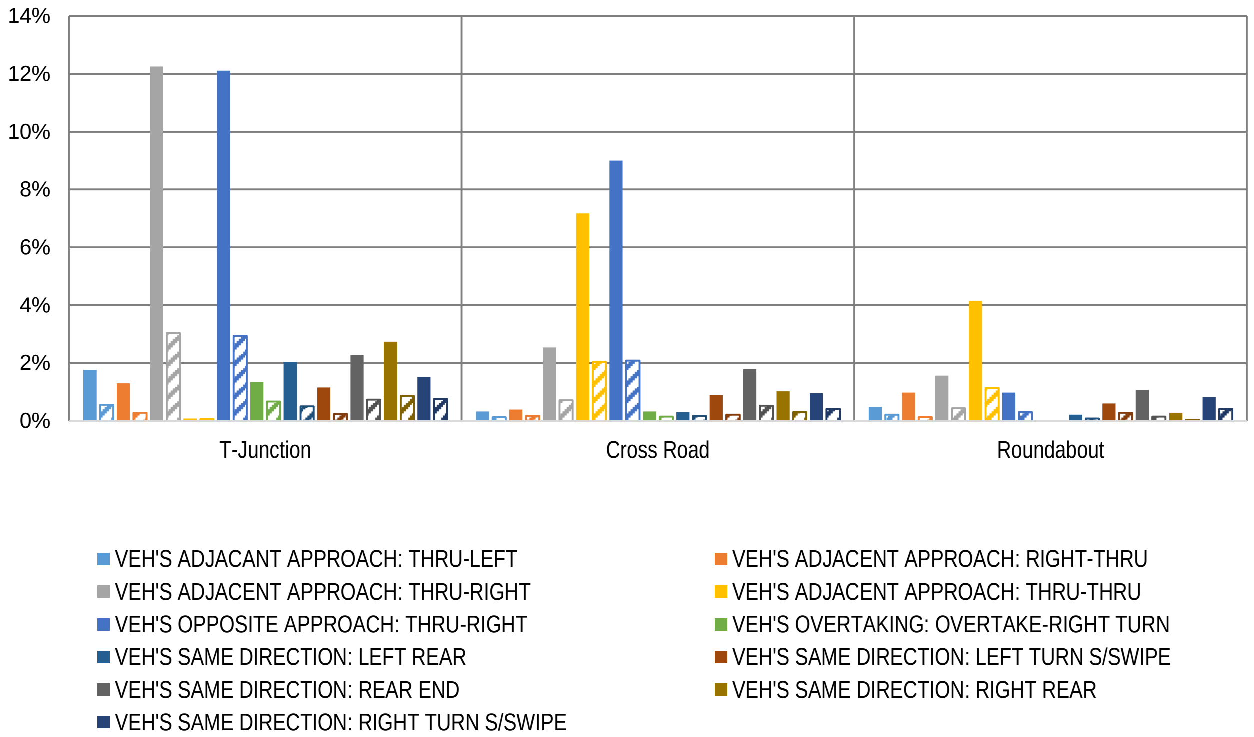
3.6.4 Intersection Motorcycle Crashes by Crash Code and Travel Purpose

It was observed (Section 1.6.3) that a majority of motorcycle crashes occur at T-junctions, crossroads and roundabouts in each jurisdiction. Further analysis of these intersection types has been undertaken to identify crash codes by crash period in each jurisdiction.

Figure 3.25 shows the distribution of motorcycle crashes at intersections in Queensland, by intersection type, crash description and crash period. The analysis shows that:

- The majority of crashes (78%) occurred in the commuting period:
  - the distribution of crashes was 39%, 27% and 12% at T-junctions, crossroads and roundabouts respectively
- The minority of crashes (22%) occurred in the recreational period:
  - the distribution of crashes was 11%, 8% and 3% at T-junctions, crossroads and roundabouts respectively
- There were more crashes at the intersections during the commuting period compared to the recreational period.
- The most represented crashes were:
  - at T-junctions in the commuting period; vehicle’s adjacent approach (thru-right) and vehicle’s opposite approach (thru-right)
  - at crossroads in the commuting period, vehicle’s opposite approach (thru-right) and vehicle’s adjacent approach (thru-thru)
  - at roundabouts in the commuting period, vehicle’s adjacent approach (thru-thru)
  - these crash types were also prominent crashes for each intersection type in the recreational period.

Figure 3.25: Queensland motorcycle crashes at key intersection types by crash description

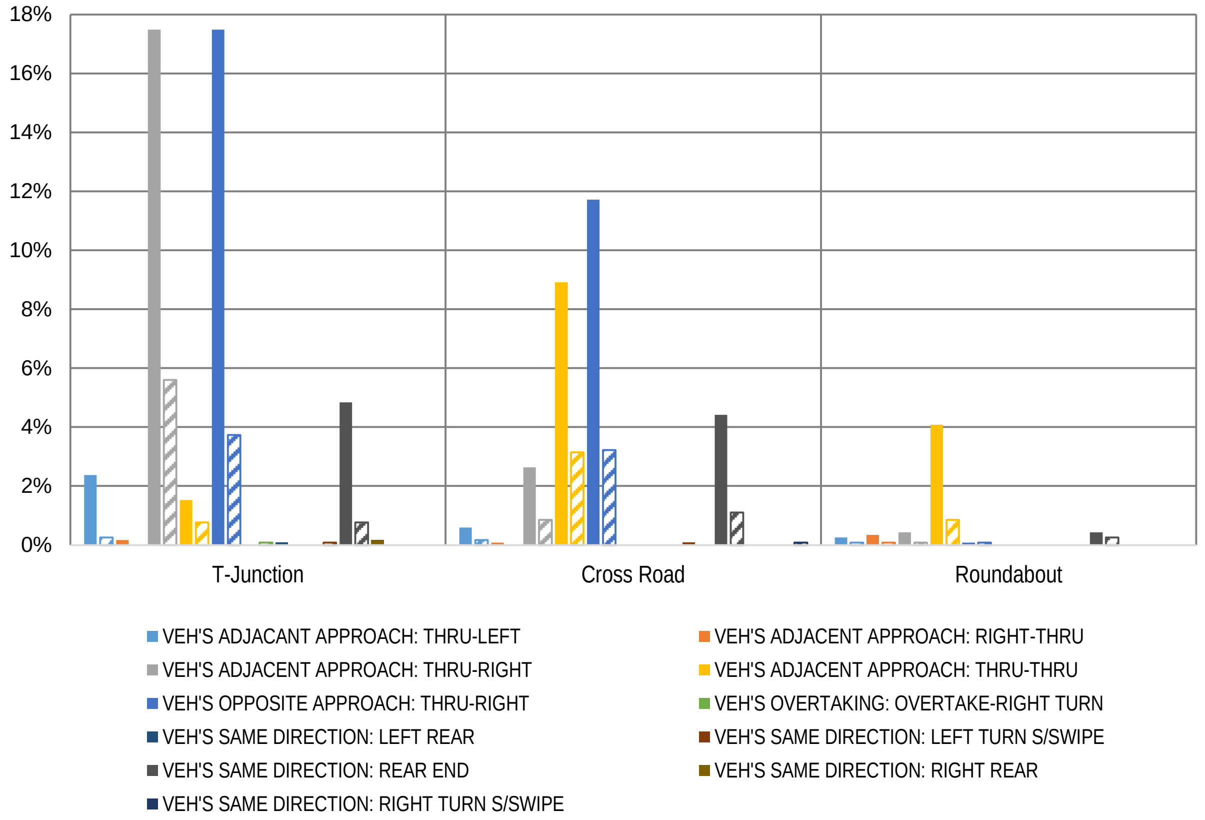


Notes:
Crashes are distributed by intersection type, and crash period. All crashes in this graph equal 100%.
The solid line represents the commuting period and the hatched line represents the recreational period.

Figure 3.26 shows the distribution of motorcycle crashes at intersections in South Australia, by intersection type, crash description and crash period. The analysis shows that:

- The majority of crashes (79%) occurred in the commuting period:
  - the distribution of crashes was 44%, 29% and 6% at T-junctions, crossroads and roundabouts respectively
- The minority of crashes (21%) occurred in the recreational period:
  - the distribution of crashes was 11%, 8% and 2% at T-junctions, crossroads and roundabouts respectively
- There were more crashes at the intersections during the commuting period compared to the recreational period.
- The most represented crashes were:
  - at T-junctions in the commuting period; vehicle's adjacent approach (thru-right) and vehicle's opposite approach (thru-right)
  - at crossroads in the commuting period, vehicle's adjacent approach (thru-thru) and vehicle's opposite approach (thru-right)
  - at roundabouts in the commuting period, vehicle's adjacent approach (thru-thru)
  - these crash types were also prominent crashes for each intersection type in the recreational period.

Figure 3.26: South Australian motorcycle crashes at key intersection types by crash description

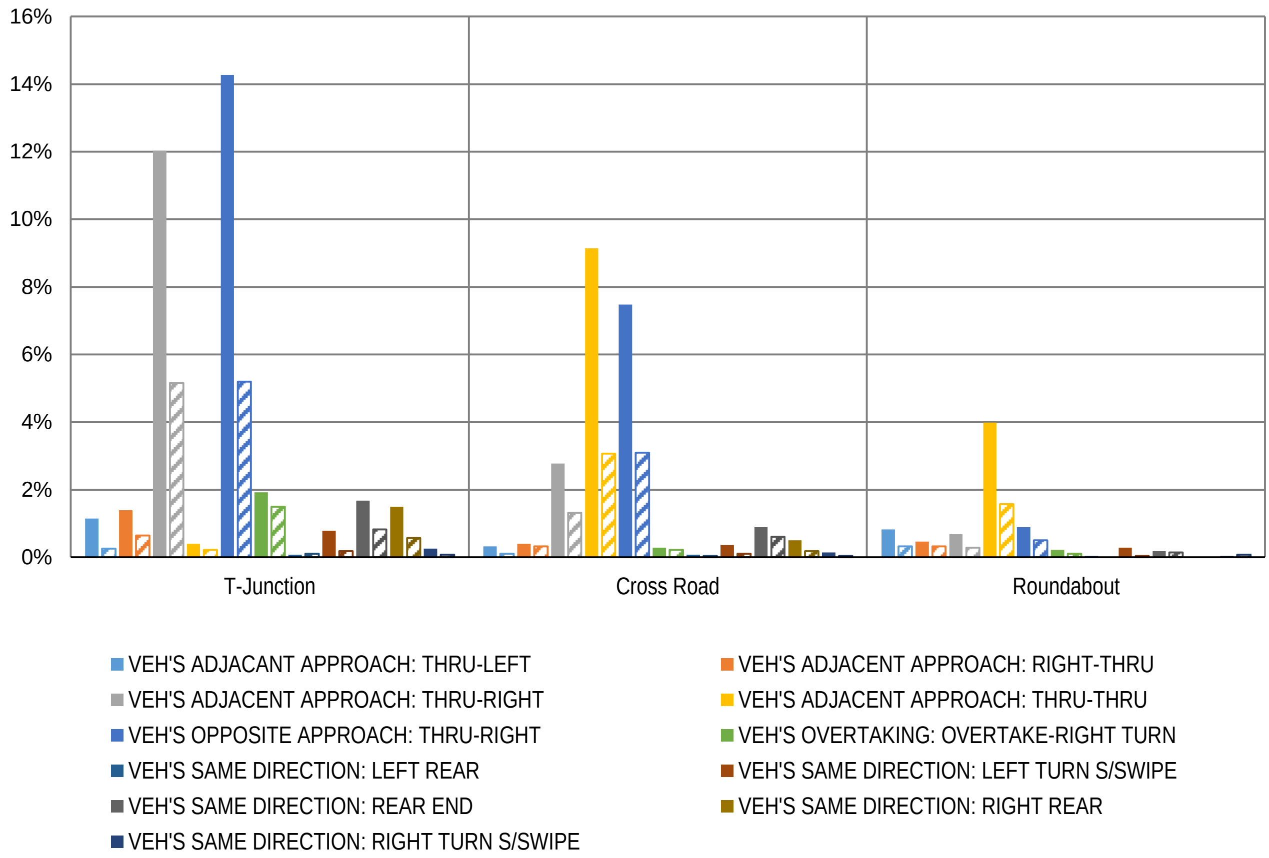


Notes:
Crashes are distributed by intersection type, and crash period. All crashes in this graph equal 100%.
The solid line represents the commuting period and the hatched line represents the recreational period.

Figure 3.27 shows the distribution of motorcycle crashes at intersections in New Zealand, by intersection type, crash description and crash period. The analysis shows that:

- The majority of crashes (71%) occurred in the commuting period:
  - the distribution of crashes was 44%, 29% and 6% at T-junctions, cross roads and roundabouts respectively
- The minority of crashes (29%) occurred in the recreational period:
  - the distribution of crashes was 11%, 9% and 2% at T-junctions, cross roads and roundabouts respectively
- There were more crashes at the intersections during the commuting period compared to the recreational period.
- The most common crashes were:
  - at T-junctions in the commuting period; vehicle’s adjacent approach (thru-right) and vehicle’s opposite approach (thru-right)
  - at cross roads in the commuting period, vehicle’s adjacent approach (thru-thru) and vehicle’s opposite approach (thru-right)
  - at roundabouts in the commuting period, vehicle’s adjacent approach (thru-thru)
  - these crash descriptions were also the prominent crashes for each intersection type in the recreational period.

Figure 3.27: New Zealand motorcycle crashes at key intersection types by crash description



Notes:
Crashes are distributed by intersection type, and crash period. All crashes in this graph equal 100%.
The solid line represents the commuting period and the hatched line represents the recreational period.

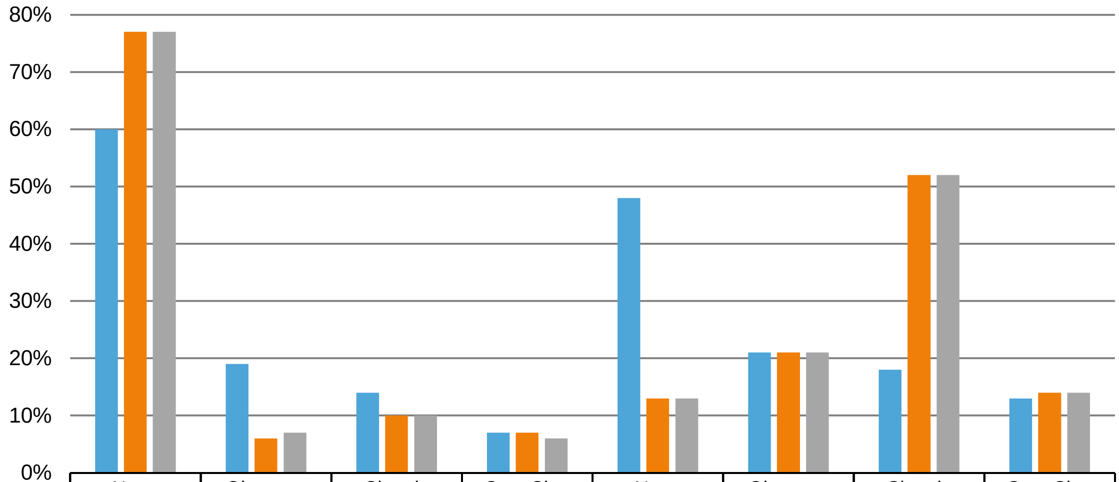
3.6.5 Intersection Motorcycle Crashes by Intersection Control

It was observed in the analysis of motorcycle crashes at intersections (Section 3.6.4) that a majority of crashes occur at T-junctions, crossroads and roundabouts. As roundabouts generally are controlled by a give way provision only T-junctions and roundabouts have been analysed.

Figure 3.28 shows the distribution of motorcycle crashes at key intersections, by intersection control. The analysis shows that at:

- T-junctions:
  - the majority of crashes (60–77%) occur when there are no intersection controls
  - approximately 10–14% of crashes occur when traffic signals are in place.
- Crossroads:
  - the majority of crashes (52%) occur when there are traffic controls (SA and NZ) and where there is no traffic control (QLD)
  - approximately 35% of crashes occur when either a stop or give way provision is in place.

Figure 3.28: Motorcycle crashes at key intersection types by intersection control



	None	Give way	Signals	Stop Sign	None	Give way	Signals	Stop Sign
	T-junction				Crossroad			
Queensland	60%	19%	14%	7%	48%	21%	18%	13%
South Australia	77%	6%	10%	7%	13%	21%	52%	14%
New Zealand	77%	7%	10%	6%	13%	21%	52%	14%

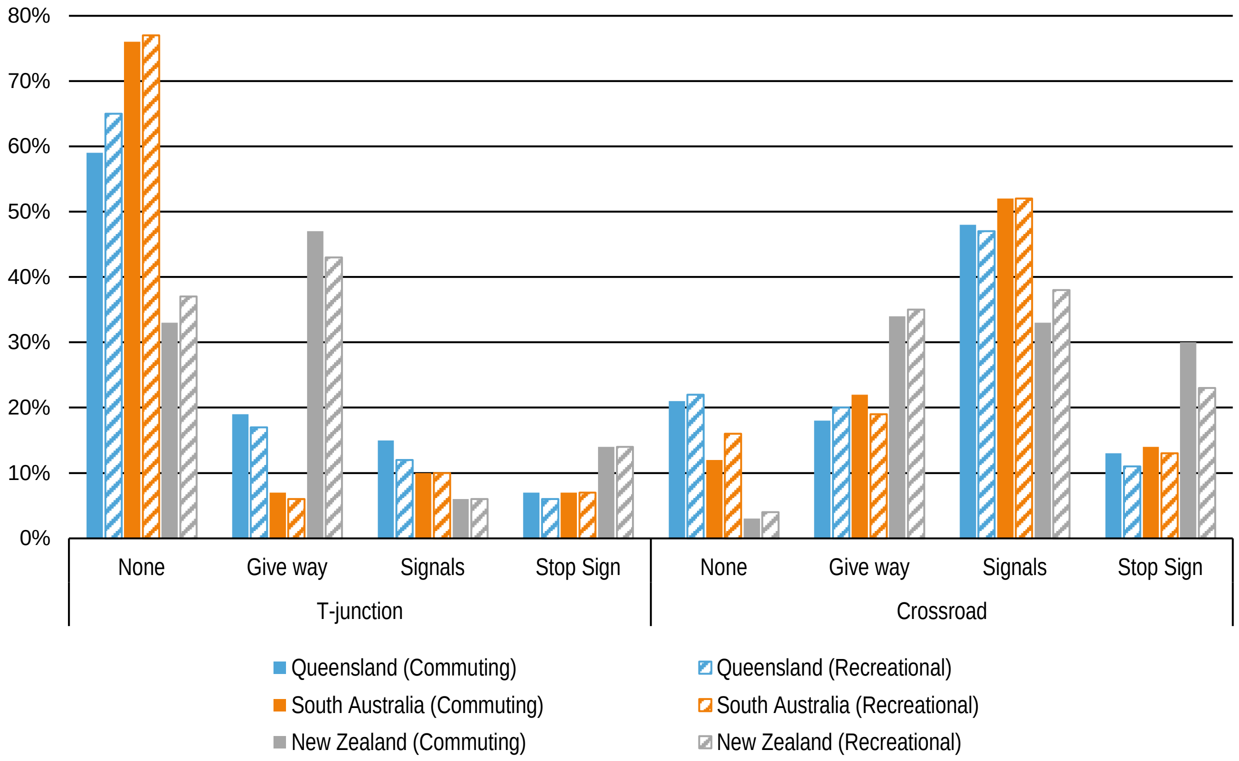
Note: Crashes are distributed by intersection type and intersection control. The crashes shown for each intersection type in each jurisdiction equal 100%.

3.6.6 Intersection Motorcycle Crashes by Intersection Control and Travel Purpose

As roundabouts generally are controlled by a give way provision only T-junctions and roundabouts have been analysed.

Figure 3.29 shows the distribution of motorcycle crashes at key intersections, by intersection control and crash period. The analysis shows that the number of crashes for each intersection control at each intersection type in that occur in commuting or recreational periods are reasonably similar.

Figure 3.29: Motorcycle crashes at key intersection types by intersection control and travel purpose



Note: Crashes are distributed by intersection type and intersection control. The crashes shown for each intersection type in each jurisdiction equal 100%.

3.7 Key Findings of the Crash Analysis

The analysis of injury crashes (including fatal crashes) identified a number of trends in relation to motorcycle crashes. These include relationships between crash period (commuting and recreational periods), road feature (curve, straight and intersection), horizontal and vertical geometry, and intersection type.

3.7.1 Vehicle and Motorcycle Crash Rates

When considering vehicle and motorcycle fatal or serious injury crashes, motorcycle crash rates were generally 3–5 times higher than for passenger vehicles. When examining injury crashes (including fatal crashes) the motorcycle crash rates were found to be 8–10 times higher than for passenger vehicles.

3.7.2 Single and Multiple Vehicle Crashes

The majority of motorcycle crashes were multiple vehicle crashes. The proportion of motorcycle crashes that were single vehicle, motorcycle only crashes was higher than the proportion of single vehicle, vehicle only crashes.

3.7.3 Commuting or Recreational Period Crashes

The number of motorcycle crashes differed depending on the crash period:

- A majority of motorcycle crashes occurred during the commuting period.
- A higher proportion of motorcycle only crashes occurred during the recreational period.
- In the recreational and commuting periods the proportion of multiple vehicle, motorcycle crashes was higher than single vehicle, motorcycle only crashes.

3.7.4 Crashes by Road Feature

It was shown that crashes differed by road feature (curve, straight and intersection). Additionally crashes on each road feature differed by travel purpose:

- A higher proportion of motorcycle crashes occurred on curves during recreational periods.
- A higher proportion of motorcycle crashes occurred on straights and intersections during the commuting period.
- Motorcycle only and multiple vehicle crashes involving a motorcycle were higher on curves during the recreational period.
- Motorcycle only and multiple vehicle crashes involving a motorcycle were higher on straights and intersections during the commuting period.
- A higher proportion of single vehicle, motorcycle only crashes occurred at intersections compared to single vehicle, vehicle crashes at intersections.

3.7.5 Mid-block Crashes

It was shown that motorcycle crashes on the midblock differed by road geometry (curve, straight, crest, dip, grade or level ground). Additionally crashes on each road geometry type differed in each crash period:

- Horizontal geometry:
  - single vehicle, motorcycle on crashes
    - in the commuting period a higher proportion of motorcycle only crashes occurred on curves with an open view, compared to curves with an obscured view
    - in the recreational period a higher proportion of motorcycle only crashes occurred on curves with an obscured view, compared to curves with an open view
    - a higher proportion of motorcycle only crashes occurred on a straight in the commuting period compared to the recreational period
  - multiple vehicle, crashes involving a motorcycle
    - a higher proportion (approximately double) of crashes involving a motorcycle occurred on curves (obscured or open view) during the recreational period compared to the commuting period
    - the proportion of crashes involving a motorcycle on curves with open or restricted views was similar for both commuting and recreational periods

- Vertical geometry:
  - single vehicle, motorcycle only crashes
    - the majority of crashes occurred on level ground, followed by crashes on a grade
    - more crashes occurred on a grade during the recreational period compared to the commuting period
  - multiple vehicle, crashes involving a motorcycle
    - most crashes occurred on level ground, followed by on a grade
    - a higher proportion of crashes on level ground occurred during the commuting period compared to the recreational period
    - a higher proportion of crashes involving motorcycles on grades occurred during the recreational period than during the commuting period
- the majority of mid-block crashes by crash group description were:
  - curve – off path on curve and head-on (lost control and swinging wide)
  - straight – off path on straight, rear-end, manoeuvring – U-turn and right turn against.

3.7.6 Intersection Crashes

Motorcycle crashes at intersections differed by intersection type and crash period:

- The majority (92–99%) of motorcycle crashes at intersections, occurred at a T-junction, followed by cross roads, then roundabouts.
- The majority of crashes where multiple vehicle, crashes involving a motorcycle, during the commuting period occurred at T-junction, followed by crossroads.
- The highest proportion of crashes in the recreational period occurred at a T-junction.
- The highest proportion of single vehicle, motorcycle only crashes occurred in in the commuting period at a T-junction.
- The majority of intersection crashes by crash description were:
  - T-junction – vehicles adjacent approach (thru-right) and opposite approach (thru-right)
  - crossroads – vehicles opposite approach (thru-right) and adjacent approach (thru-thru)
  - roundabouts – vehicles adjacent approach (thru-thru).

4. Road Infrastructure as a Crash Factor

Road infrastructure is often a factor in motorcycle crashes. As identified in the literature review, and in a number of motorcycle specific road safety audits as undertaken by ARRB Group (Milling & McTiernan 2014) infrastructure elements can influence the likelihood of a crash occurring or the resulting severity of a crash. The condition, presence or location of a road infrastructure element can directly or indirectly cause a motorcycle crash, e.g. a pothole on a curve may cause a motorcyclist to lose control resulting in a run-off road crash or it may redirect the motorcyclist across the centreline into the path of an oncoming vehicle resulting in a head-on crash.

Table 4.1: Road infrastructure elements that may be a factor in motorcycle crashes

Crash likelihood		Crash severity
Midblock	**Intersections**	**Midblock and intersection**
Road alignment Sight distance Curve quality Overtaking provisions Skid resistance/surface texture Surface hazards Carriageway width Signage and delineation Surface condition Roadworks	Intersection type Line of sight Turning provisions Horizontal geometry Advance signage Carriageway width Road surface texture, drainage, condition and hazards	Roadside furniture Safety barriers Utility services Drainage Natural environment Landscaping

Note: The road elements contributing to crash likelihood for midblock may also apply to intersections.

A number of different road infrastructure elements can contribute towards motorcycle crash risk. These can be isolated elements or an aggregation of elements. Some examples of how the condition, presence or location of road infrastructure elements can contribute to crashes are:

- poor sight lines, signage and delineation which can reduce the readability of the road, thus increasing the complexity of the riding task
- poor pavement condition including rutting, surface deformations, surface texture or skid resistance may destabilise the motorcycle or redirect its intended travel direction
- the location, size and type of roadside object can affect the severity of the crash.

Road infrastructure elements contributing to motorcycle crashes have been collected from various motorcycle safety guides produced by road agencies nationally and internationally as well as from branches of the Australian Motorcycle Council. Additional safety issues from motorcycle specific road safety audits conducted by ARRB Group in South Australia, New South Wales and Queensland were also included.

The road infrastructure crash factors in the AusRAP model for motorcycles have been reviewed including a comparison between the risk factors for motorcycles and passenger vehicles. The motorcycle crash factors from AusRAP and their associated risk factors have been used to model the influence road infrastructure elements have on motorcycle crash risk, particularly when these elements vary in condition, thus having different risk factors.

4.1 Infrastructure Effects on Motorcycle Performance

4.1.1 Operating a Motorcycle

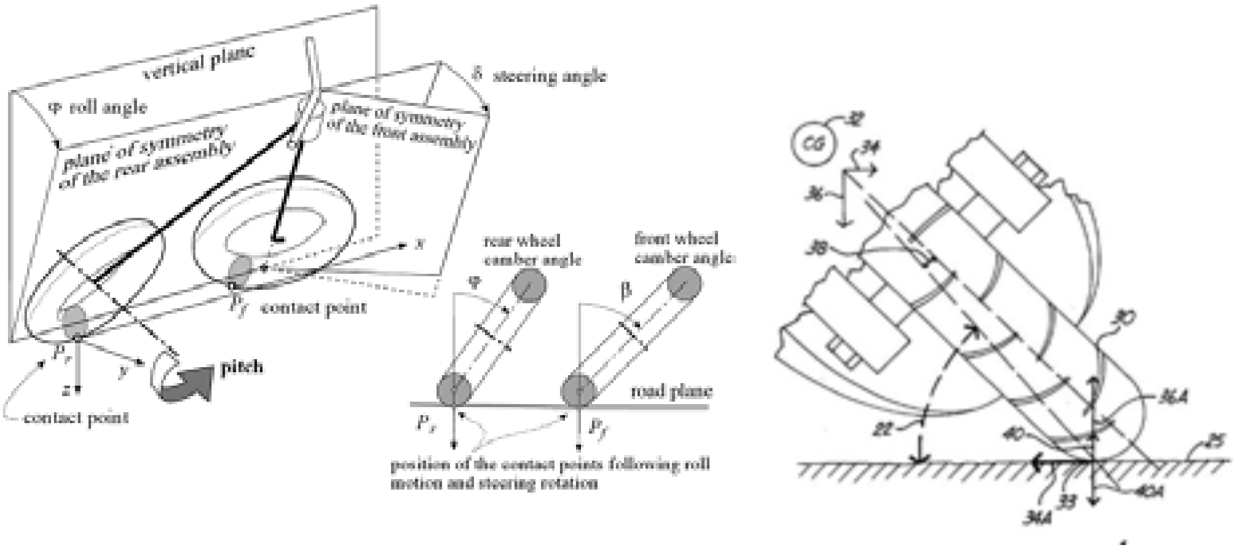
A motorcycle has different handling and braking characteristics to passenger cars. Motorcycles are comparatively complex to operate, particularly when turning (at both high and low speeds) and when applying emergency braking. Perhaps the most demanding task faced by a motorcyclist is applying emergency braking whilst turning or undertaking evasive action. When braking, accelerating or indicating, a motorcyclist is required to perform the following tasks, sometimes simultaneously:

- **Braking:** even braking distribution is achieved through the right hand (front brake) and the right foot (rear brake), this is essential to maintain stability whilst braking (Section 4.1.2). The right hand controls both the front brake and the throttle, if the right hand is not rotated forward (throttle 'shut off') whilst braking, power will continue to be driven through the rear wheel resulting in the motorcycle losing control.
- **Accelerating:** accelerating from a stop-start is achieved by twisting the throttle with the right hand, operating the clutch with the left hand and changing gears with the left foot. Often the twist of the throttle and using the clutch is required whilst the left or right hand is pushing the handle bars to turn. Twisting the throttle too much whilst turning often results in loss of control as it does if acceleration is not 'shut off' when braking.
- **Indicating/horn/high beam:** the control assembly is often next to the left hand. Whilst a motorcyclist is pushing the handle bars (to turn) or controlling the clutch, the activation/cancelation of the indicator is carried out with the left thumb. This may impede the left hand's ability to control the clutch and turn the bike.
  - Some motorcycles have a second indicator activation/cancelation switch on the right hand grip for the right indicator. The switch on the right hand grip greatly impedes the right hand control, particularly if it is being used to control the indicator whilst the throttle is active. Taking the hand off the throttle or using throttle 'shut off' to control the indicator switch will result in engine braking and the motorcycle decelerating. Controlling the indicator switch whilst the throttle is active may result in over-acceleration and loss of control.

4.1.2 Operating a Motorcycle and the Interaction with Road Infrastructure

Motorcyclists place a high reliance on road infrastructure. A motorcycle has reduced contact with the road as it has only two tyres, with smaller contact patches contacting the road and is required to lean and in some cases counter steer whilst turning and cornering (Figure 4.1). The handling characteristics and resulting stability of a motorcycle on a curve vary greatly to a passenger vehicle. A passenger vehicle's suspension ensures the tyres remain upright (Figure 4.2) resulting in a passenger vehicle being less likely than a motorcycle to lose friction when turning or cornering.

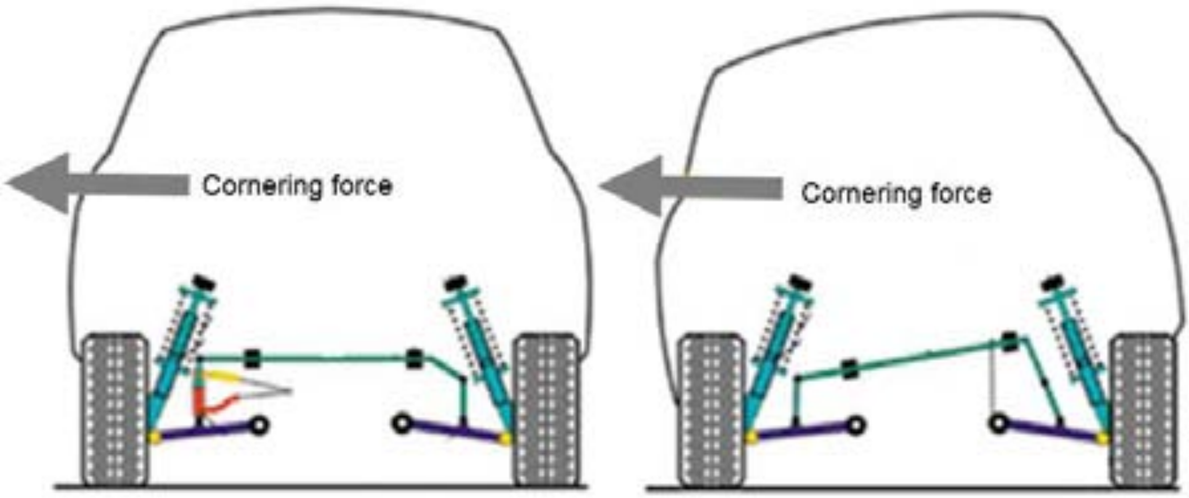
Figure 4.1: Motorcycle handling characteristics on a curve – countersteering and motorcycle lean



Countersteering *Motorcycle lean*

Source: Cossalter (2006).

Figure 4.2: Passenger vehicle handling characteristics on a curve



With active roll control *Without active roll contro*

Source: Jost (2001). Active roll control.

Some examples of why a motorcycle is more vulnerable than a passenger car due to its handling characteristics and interaction with infrastructure are as follows:

- A motorcycle has less contact points with the road surface. Any loss of friction (grip) between the front or rear tyre and the road surface whilst braking, turning or negotiating a curve is likely to destabilise a motorcycle. A motorcycle has a higher reliance on a hazard free road surface with adequate and consistent skid resistance and surface texture. When a combination of braking and turning or negotiating a curve and braking occurs, the reliance on the road surface is higher.
- Stopping distances are dependent on a motorcyclist's skill level, perceived (wet weather, polished surface) and actual skid resistance of the pavement surface and resulting applied brake pressure. A motorcyclist will brake at a deceleration rate appropriate to their riding ability (Davoodi & Hamid 2013).
- Braking and swerving result in weight shift due to suspension compression and the transfer of a motorcyclist's weight which affects motorcycle stability.

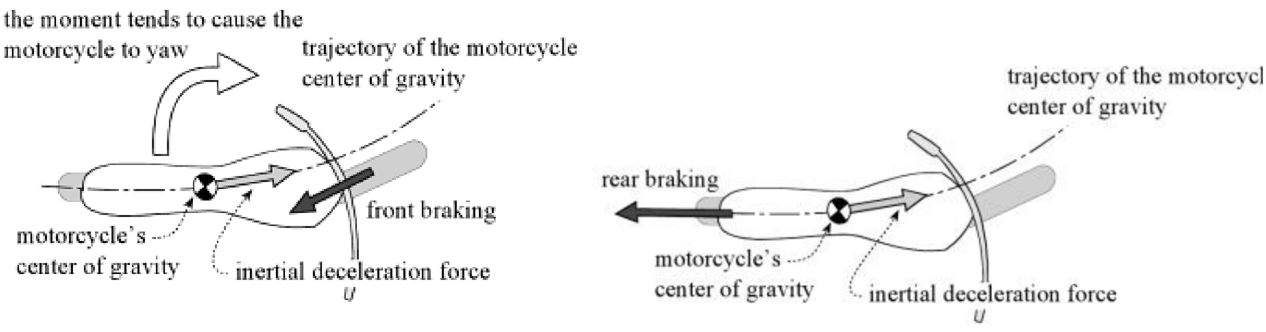
- Motorcycle stability whilst braking on a straight or a curve is dependent on a motorcyclist's skill level and the pressure applied to the front and rear brakes, as well as the steer angle of the front wheel and a variation of front and rear wheel braking if the motorcycle is turning and leant over. If braking is heavier on the front wheel than the rear wheel when turning, the rear of the motorcycle may pivot in the forward direction destabilising the motorcycle (Figure 4.3).
- A motorcyclist applying heavy braking on a curve is likely to straighten and continue on a tangent whilst decelerating.
- A motorcycle without brake assist, anti-lock braking or stability control technologies is more reliant on a hazard free road surface with adequate and consistent surface texture (Figure 4.4).
- A motorcycle is required to lean whilst cornering. Whilst turning, a leaning motorcycle places a higher reliance on a hazard free road surface with adequate and consistent surface texture, particularly where there is also an adverse crossfall (camber).
- The motorcycle lean angle is proportional to the motorcycle speed and curve radius. As the motorcycle speed increases (relative to the posted speed limit) and the curve radius decreases the lean angle increases as does the reliance on the road surface.
  - The clearance between the motorcycle and the road surface reduces as the lean angle increases (Figure 4.5).
  - The clearance between the motorcycle and the road surface is less on turns and curves with adverse crossfall (Figure 4.6).
- Where a motorcycle is required to counter-steer (Figure 4.7) to negotiate high speed or low speed curves or to make a turn at an intersection or property entrance, there is a higher reliance on a hazard free road surface with adequate and consistent surface texture:
  - The steer angle of the front tyre and lean angle of the motorcycle whilst turning or braking increases a reliance on adequate surface friction, particularly when braking as well.
- An object, surface deficiency or hazard can redirect the front or rear wheel of a motorcycle which affects the stability and direction of travel.
- An object, surface deficiency or hazard may be avoided by undertaking risky evasive manoeuvres.
- An unclear and unreadable road alignment and environment can result in more drastic manoeuvres to change a riding path to negotiate the road alignment or avoid a hazard (fauna, surface hazard or other vehicle) as braking and swerving are introduced concurrently.

As a result of the unique handling characteristics of a motorcycle, a number of road infrastructure elements have a greater effect on motorcycle crash risk than on passenger vehicle crash risk. Any crash factor that affects how a motorcycle performs can be combined with other road infrastructure elements that influence motorcyclist behaviour which creates an exponential effect. An example of the effects of crash factors on motorcycle performance or rider behaviour is provided in Table 4.2.

Table 4.2: Crash likelihood factors affecting motorcycle performance or motorcyclist behaviour

Crash description	Crash factors	
	Likely to affect motorcycle performance	Likely to affect motorcyclist behaviour
Motorcycle loss of control on curve	Lane width, curve radius, superelevation/adverse crossfall, surface texture (loss of grip whilst motorcycle is leant over), surface hazards, surface condition, grade	Curve warning signage and delineation, shoulder rumble strips, surface texture (loss of grip whilst motorcycle is leant over), sight lines
Passenger vehicle turns from side road in front of motorcycle on through road	Intersection type, grade, lane width, skid resistance, surface hazards, surface condition	Intersection design (speed reduction on approaches), clarity of intersection layout, advance signage, intersection control, street lighting, sight distance

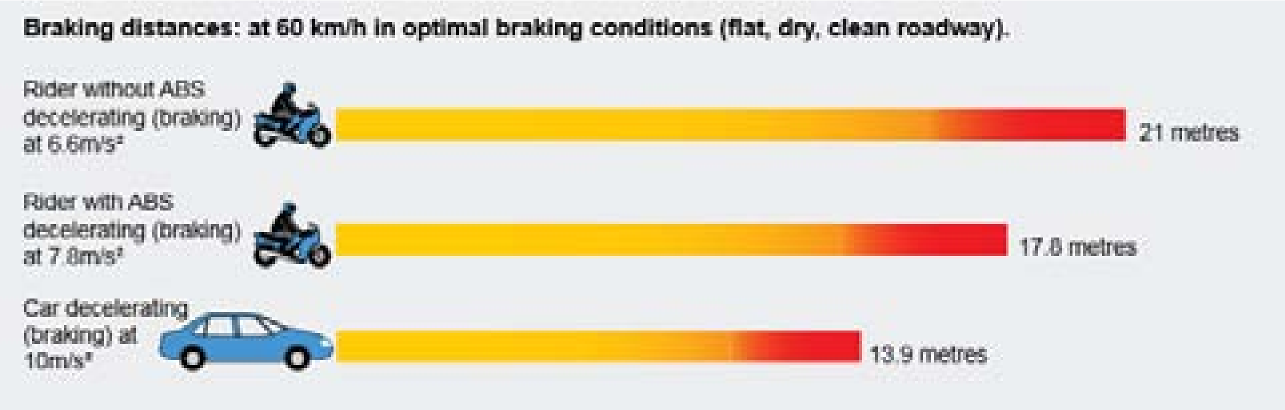
Figure 4.3: Effects of applying front and rear brakes on left turn/curve



Effects of applying front brake *Effects of applying rear brake*

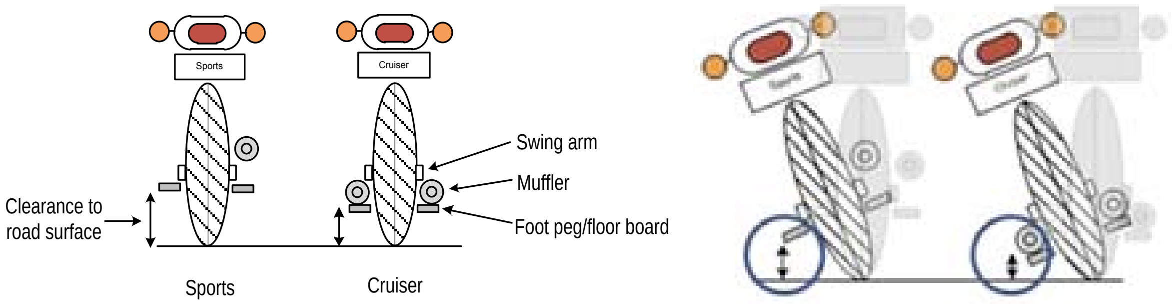
Source: Cossalter (2006).

Figure 4.4: Motorcycle and vehicle stopping distances



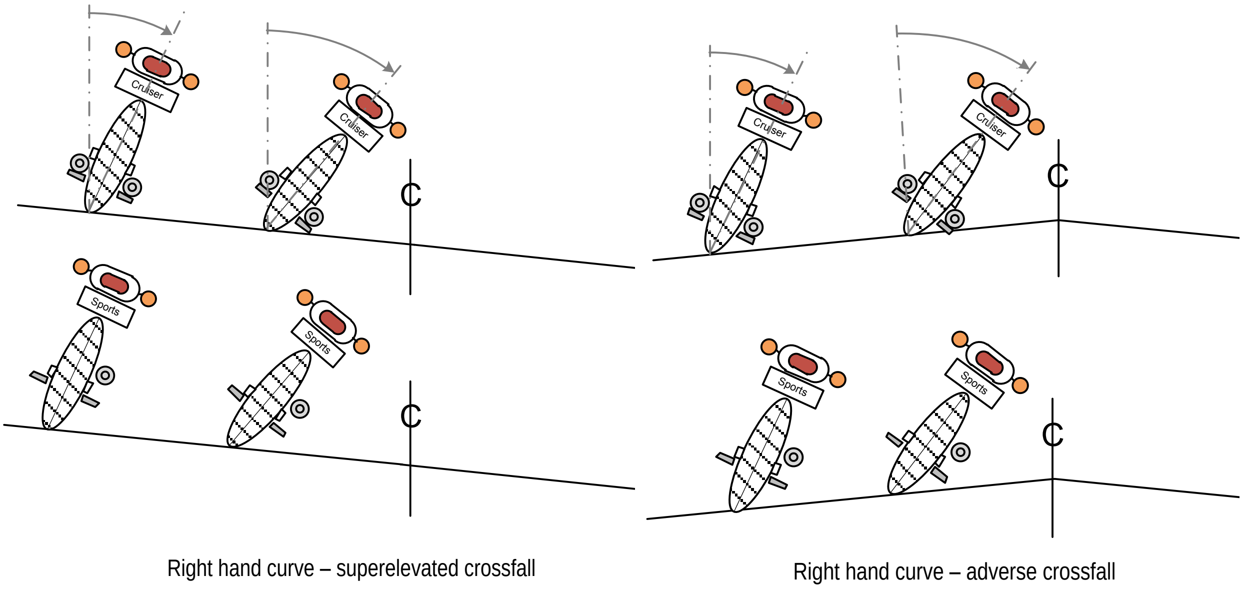
Source: Roads and Maritime Services (2012).

Figure 4.5: Clearance between the road surface and the lowest point of a motorcycle



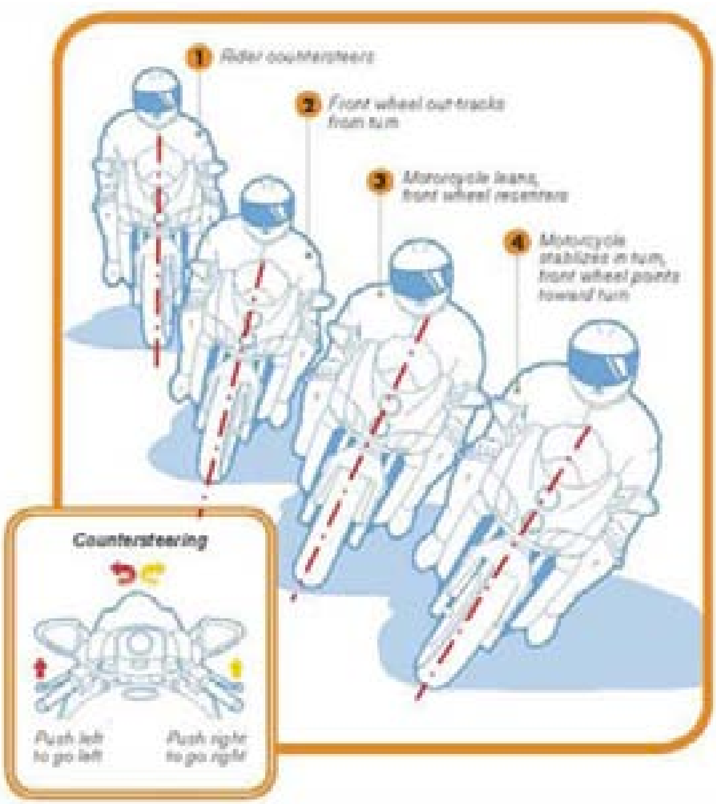
Notes:
These are indicative positions for foot pegs and mufflers, however, they are representative of motorcycle types.
The clearance to the ground decreases when a motorcycle leans to turn or negotiate a curve.
This figure also applies for left and right hand turns/curves.

Figure 4.6: Motorcycle clearance on curves



Notes:
This figure also applies for left hand curves.
A cruiser is more likely to contact the road surface when the lean angle is increased, particularly on curves with adverse crossfall.
A sports motorcycle is more likely to contact the road surface on a curve with adverse crossfall.

Figure 4.7: Motorcycle countersteering



Note: Countersteering is where the front tyre is turned in the opposite direction of the curve/turn required to tilt the motorcycle into the lean angle.
Source: Lindemann (2013).

4.2 Crash Factors by Road Engineering Discipline

Road infrastructure elements may or may not be a crash factor in a motorcycle crash. The design and consistency of design attributes, the use of signs and lines and the standard that these are maintained to road infrastructure being a crash factor in motorcycle crashes. The unique road infrastructure needs that motorcycles require to operate safely should be considered across all road engineering disciplines, this is inclusive of:

- network planning and road design
- asset management programming
- maintenance practices and workmanship.

Some common road infrastructure elements that contribute to motorcycle crash risk are shown in Table 4.3 and Table 4.4. In these tables the element is attributed to a road engineering discipline. Some examples of what may be considered when attributing an element to each discipline are as follows:

- **Road design** – The design may not have considered the needs of a motorcyclists during the design process. Combinations of elements may be suitable for passenger vehicles but not motorcycles.
- **Asset management programming** – Typically asset management programing, does not specifically manage road elements that most affect motorcycle crash risk.
- **Maintenance practices** – Deficiencies on the road that most affect motorcycle crash risk are not prioritised. The quality of workmanship may also increase motorcycle crash risk.
- **Road safety assessments** – Proactively identify motorcycle crash risk through road assessment programs, e.g. AusRAP and motorcycle specific road safety audits.

Table 4.3: Midblock road infrastructure elements affecting the likelihood of a motorcycle crash by engineering discipline

Road infrastructure element	Design	Asset management/ maintenance	Road safety assessments	Examples
Road alignment	✓		✓	Horizontal and vertical curve types, radius, combinations and frequency of changes in the alignment
Sight distance	✓	✓	✓	Horizontal and vertical sight distances restricted due to cuttings and the alignment
Curve quality	✓	✓	✓	Signage and delineation to identify the direction of the alignment and severity of a curve
Overtaking provisions	✓		✓	Frequency of safe overtaking opportunities
Surface friction	✓	✓	✓	Low surface friction pavements and pavement markings, loss of surface friction due to wear and tear (polishing, flushing, crack sealant) and poor drainage (surface water, moss, ice)
Surface hazards	✓	✓	✓	Service pit covers, speed humps, tram/train tracks, raised kerbs, water, poor repair work, edge drop and foreign material
Carriageway width	✓	✓	✓	Lane and shoulder width, particularly on curves, have an effect on riding paths and the distance from a roadside hazard or vehicle in the opposing lane. Shoulder width, condition and if sealed or unsealed
Signage and delineation	✓	✓	✓	Line marking, pavement arrows, guide posts, warning signs and advance direction signs
Surface condition		✓	✓	Delamination, potholes, rutting and corrugations
Roadworks		✓	✓	Temporary alignment, pavement changes, loose gravel, rough surfaces and steel plates
Roadside hazards	✓		✓	Guardrail, parked cars, utility poles, sign posts and drainage structures

Table 4.4: Intersection road infrastructure elements affecting the likelihood of a motorcycle crash by engineering discipline

Road infrastructure element	Design	Asset management/ maintenance	Road safety assessments	Examples
Intersection type	✓		✓	Clarity of intersection layout, intersection control and number of conflict points as a result of intersection type/controls
Turn provisions	✓		✓	Presence of and type of turn provision separating turning and through traffic and movements through the intersection
Intersection location	✓		✓	An intersection on a downgrade or curve results in a more complex riding task, particularly if avoiding a collision
Lighting and delineation	✓	✓	✓	Clarifying the intersection layout and raised kerbing at night
Advance signage	✓	✓	✓	Clarity of information about route directions allows low risk manoeuvres to change lanes or decelerate to turn
Sight distance	✓	✓	✓	Sight lines for the side road and through road allow a motorcyclist to make early and informed decisions
Carriageway width	✓	✓	✓	The lane and shoulder width affects manoeuvring distance for a motorcycle to safely stand clear of traffic before turning or to manoeuvre around a potential collision. Shoulder width, condition and if sealed or unsealed
Surface friction	✓	✓	✓	Low surface friction pavements and pavement markings, loss of surface friction due to wear and tear (polishing, flushing, crack sealant) and poor drainage (surface water, moss, ice)
Surface condition		✓	✓	Delamination, potholes, rutting and corrugations
Surface hazards	✓	✓	✓	Service pit covers, tram/train tracks, raised kerbs, water and foreign material
Roadworks		✓	✓	Temporary alignment, pavement changes, loose gravel, rough surfaces and steel plates
Roadside hazards	✓		✓	Guardrail, parked cars, power poles, sign posts, signals, pedestrian fencing and drainage structures

4.3 Assessing Motorcycle Likelihood and Severity using AusRAP

The AusRAP model has the ability to calculate motorcycle risk and recommend remedial treatments. Within the model, a risk-based star rating score (SRS) is calculated for each of the various road user groups. These include passenger vehicles, motorcycles, pedestrians and cyclists. These scores are not averaged or aggregated to give a single SRS. Instead, an SRS is reported for each road user group activated during the assessment process. Currently, most assessments undertaken in Australia do not activate the motorcycle model and, therefore, motorcycle risk has not been widely analysed.

4.3.1 Risk Factors – Difference between Vehicles and Motorcycles

The AusRAP model shows that for a number of attributes the motorcycle crash likelihood (Table 4.5) and severity (Table 4.6) factors are higher than their equivalents for a passenger vehicle. The higher factors for motorcycles reflect what was found in the crash analysis (Section 3), particularly with regard to risk on curves and at intersections.

The attributes which lead to higher motorcycle crash likelihood are:

- curvature (the horizontal alignment of the road, taking into account the radius of the curve)
- quality of curve (i.e. how easy it is to judge how 'sharp' a curve is and if it can be negotiated safely. The quality of the curve will reflect the extent to which signs and markings help the road user to 'read the curve' – judge the correct curvature and the sight distance in advance of, and around, the curve)
- road condition (the ability of the road to provide a level, even running surface free from major surface defects that may adversely affect the vehicle path)
- skid resistance and surface texture (specific characteristics of the road surface providing all important 'grip' for manoeuvres being attempted)
- intersection type (the presence and type of intersections with gazetted/adopted roads).

The attributes which lead to higher motorcycle crash severity are:

- driver-side object (e.g. an object in the median on a divided road or the right shoulder for an undivided road)
- passenger-side object (e.g. an object on the left shoulder)
- intersection type (e.g. intersection design type and resulting features such as angles of impact, sightlines, vehicle speeds, vehicle compliance, etc.).

Table 4.5: Road infrastructure elements where AusRAP likelihood risk factors for motorcycles are higher than for vehicles

Elements	Description	Likelihood risk factors (rural and urban)		Difference between vehicle and motorcycle risk factors
		Vehicle	Motorcycle	
Curvature	Moderate curvature	1.8	2	0.2
	Sharp curve	3.5	3.8	0.3
	Very sharp	6	6.5	0.5
Quality of curve	Poor	1.25	1.4	0.15
Road condition	Medium	1.2	1.25	0.05
	Poor	1.4	1.5	0.1
Skid resistance / grip	Sealed – medium	1.4	1.6	0.2
	Sealed – poor	2	2.5	0.5
	Unsealed – adequate	3	4	1
	Unsealed – poor	5.5	7.5	2.0
Intersection type	Roundabout	15	30	15
	3-leg (unsignalised) driver-side turn lane	13	17	4
	3-leg (unsignalised) no driver-side turn lane	16	20	4
	3-leg (signalised) no driver-side turn lane	12	14	2
	4-leg (unsignalised) no driver-side turn lane	23	26	3
	4-leg (signalised) no driver-side turn lane	15	16	1
Intersection quality	Readability of layout, approach signage, delineation and linemarking	0	1	1

Note: The risk factors are intended to be used within the AusRAP model only, they are shown for comparative purposes only.
Source: AusRAP test bed version 3.02, provided by International Road Assessment Programme (iRAP) (2014).

Table 4.6: Road infrastructure elements where AusRAP severity risk factors for motorcycles are higher than for vehicles

Elements	Description	Severity risk factors (rural and urban)		Motorcycle risk factor is greater by
		Vehicle	Motorcycle	
Driver-side object	Safety barrier – metal	12	30	18
	Safety barrier – concrete	15	25	10
	Safety barrier – metal mc friendly	12	20	8
	Safety barrier – wire rope	9	30	21
Passenger-side object	Safety barrier – metal	12	30	18
	Safety barrier – concrete	15	25	10
	Safety barrier – metal mc friendly	12	20	8
	Safety barrier – wire rope	9	30	21
Intersection type	Merge Lane	15	20	5
	Roundabout	15	30	15

Note: The risk factors are intended to be used within the AusRAP model only, they are shown for comparative purposes only.
Source: AusRAP test bed version 3.02, provided by iRAP (2014).

The crash likelihood due to lane width is higher on rural roads than urban roads as shown in Table 4.7.

Table 4.7: AusRAP motorcycle likelihood risk factors for lane width

Element	Description	Likelihood risk factors	
		Rural	Urban
Lane width	Wide (≥ 3.25 m)	1	1
	Medium (≥ 2.75 to < 3.25 m)	1.2	1.05
	Narrow (≥ 0 to < 2.75 m)	1.5	1.1

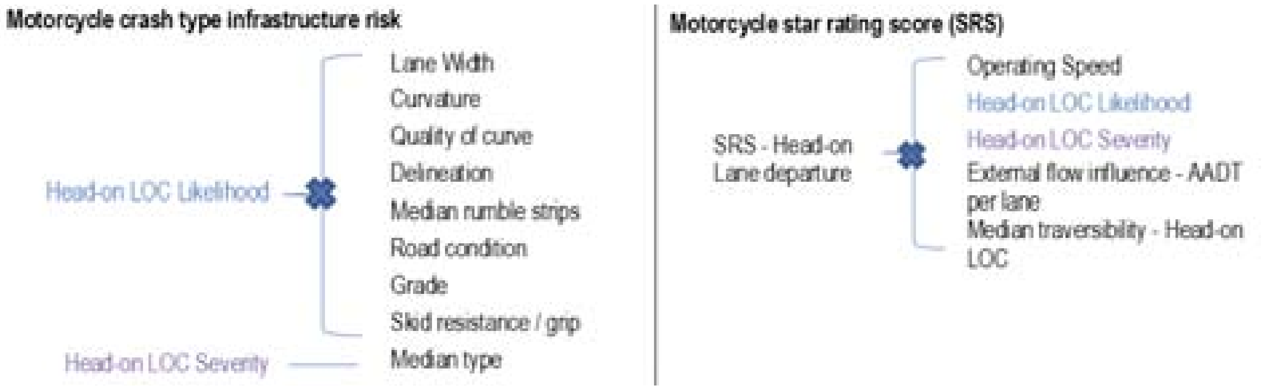
Source: AusRAP test bed version 3.02, provided by iRAP (2014).

4.3.2 Star Rating Score

The SRS is a score given to a section of road to highlight the level of safety on that section for a road user group. The SRS ranges from 1 to 5, lowest to highest, respectively. The SRS for the motorcycle model (Appendix A.1) is calculated using a combination of likelihood, severity, speed, AADT and median type. The factors contributing to the crash likelihood and severity are shown in the left column of Table 4.8 and the factors contributing the total SRS in the right column. The factors contributing to all crash types are shown in Appendix A.2.

It should be noted that these are not all the crash factors that will be identified as a result of this study, however, it is a good demonstration of a majority of the factors affecting motorcycle crash likelihood and severity.

Table 4.8: Motorcycle head-on crash type infrastructure risk and safety risk score



Note: Loss of control (LOC).
Source: AusRAP test bed version 3.02, provided by iRAP (2014).

4.4 Midblock Crash Likelihood

The road infrastructure elements that affect crash likelihood on a midblock section are summarised in Table 4.9. These are explained in further detail below.

Table 4.9: Midblock – road infrastructure elements affecting motorcycle crash likelihood

Elements	Examples
Road alignment	Horizontal and vertical curve types, radius, combinations and frequency of changes in the alignment
Sight distance	Horizontal and vertical sight distances restricted due to cuttings and the alignment
Curve quality	Signage and delineation to identify the direction of the alignment and severity of a curve
Overtaking provisions	Frequency of safe overtaking opportunities
Skid resistance/surface texture	Low surface friction pavements and pavement markings. Loss of surface friction due to wear and tear (polishing, flushing, crack sealant) and poor drainage (surface water, moss, ice)
Surface hazards	Service pit covers, speed humps, tram/train tracks, raised kerbs, water, poor repair work, edge drop, and foreign material
Carriageway width	Lane and shoulder width, particularly on curves has an effect on riding paths and the distance from a roadside hazard or vehicle in the opposing lane. Shoulder width, condition and if sealed or unsealed
Signage and delineation	Line marking, pavement arrows, guide posts, warning signs and advance direction signs
Surface condition	Delamination, potholes, rutting and corrugations
Road works	Temporary alignment, pavement changes, loose gravel, rough surfaces and steel plates

4.4.1 Road Alignment

Horizontal curves

To safely negotiate changes in the horizontal alignment (i.e. curves), an adequate level of friction must be maintained between the road surface and the vehicle tyre to prevent possible destabilisation and loss of control. Specifically, a motorcycle's stability along a curve is also affected by the steer angle of the front wheel, suspension performance, brake pressure applied to the front and rear brakes and the transfer of the motorcyclist and the motorcycle weight through the suspension. A section of road with a concentration of curves will increase the complexity of the riding task. As it is uncommon for a series of curves to be identical, changes in curve direction, curve type (reverse, compound), curve radius, superelevation and adverse crossfall significantly affect motorcycle crash likelihood.

Each curve type places different demands on a motorcycle. These increase with motorcycle speed (not the posted speed limit or curve advisory speed) and decreasing curve radius. Additionally, a change in curve direction (i.e. a double curve, where a right hand curve transitions into a left hand curve) results in these demands being amplified as the motorcyclist is required to transfer their lean from one side to the other side.

To safely negotiate a horizontal curve, a motorcycle is required to 'lean' using countersteering (also known as push steering) into a corner rather than simply turning the handlebars (Figure 4.8 and Figure 4.9). The degree to which the motorcyclist is required to lean depends on their speed and the radius of curvature. Depending on the approach and riding path a motorcyclist chooses whilst negotiating a curve, a motorcyclist may be in a position where the lean of the motorcycle required to negotiate the curve at their operating speed results in the motorcyclist leaning into the curve to such an extent that their body crosses the centreline and risks exposure to oncoming traffic. The section of the road where this could happen is called the 'head-on zone' and is shown in Figure 4.10. An experienced motorcyclist will select a riding path away from the head-on zone, however, some situations may arise (e.g. avoiding hazards in the lane) where riding in the head-on zone is unavoidable.

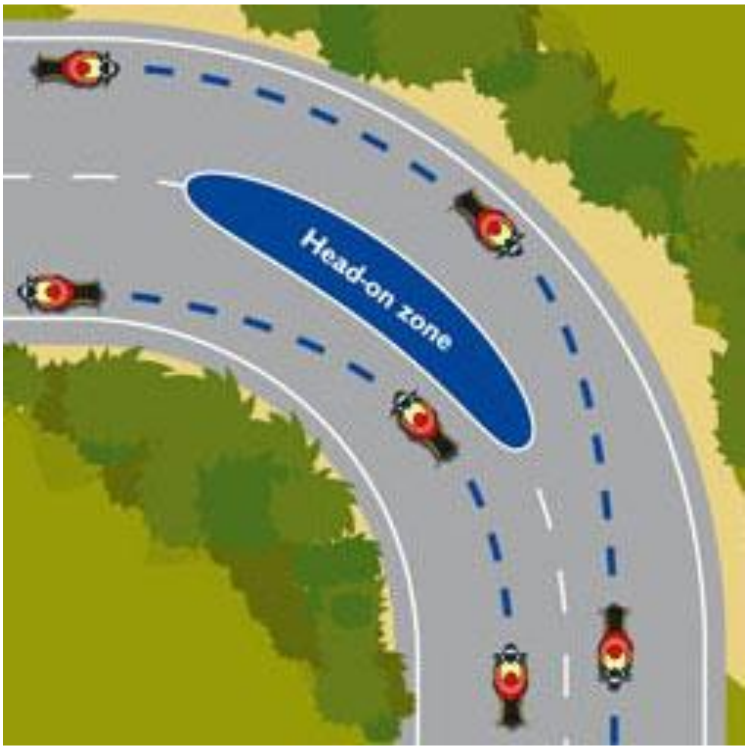
Figure 4.8: Motorcycle lean on a small radius curve

Source: EuroRAP (2008).

Figure 4.9: Motorcycle lean on a curve exit

Source: Roads and Maritime Services (2012).

Figure 4.10: Curve riding paths – head-on zone



Source: Roads and Maritime Services (2012).

Where there is little consistency in the horizontal curves on a road or route (i.e. the curves have varying radii, crossfall and superelevation, rate of rotation and curve length), each curve will be negotiated by a motorcycle differently depending upon the motorcycle speed, curve radius and the curve length.

Changes in curve radius, direction or a change from single curves to reverse curves or an isolated compound curve on a road section may result in a higher demand on the motorcycle, particularly if the motorcyclist has selected a riding path that is not suited to the curve. A change in riding path on a curve results in braking and changing direction which increases the likelihood of a motorcycle destabilising.

Motorcycle riding path

A motorcyclist will select a different riding path to negotiate each curve type. Each riding path places performance demands on the motorcycle that increase the likelihood of a motorcycle destabilising. A single radius curve will generally require the motorcycle to lean at a constant angle and travel at a constant speed with little braking whereas a compound or a reverse curve (particularly with a shared tangent point) will require the motorcycle to change lean angles, decelerate and accelerate.

An example of the most likely riding paths chosen by an experienced motorcyclist is shown in Figure 4.11, each showing the complexity of the task and a description of the riding path, namely:

- single curve – single constant steering path
- compound curve – apparent constant steering path (Figure 4.12), having to be altered and accompanied by braking or by leaning the motorcycle at more of an angle to negotiate the tightening curve. It should be noted that the presence of a tightening curve is not always apparent and can come as a surprise to a motorcyclist
- reverse curve – a riding path that consists of alternate steering paths with a planned transition point where the motorcyclist switches leaning from one side to the other side.

When approaching any curve, a motorcyclist will select a riding path based on the alignment that is perceived to be ahead. The usable lane width (affected by surface condition, surface texture and surface hazards), sight lines through the curve and whether the curve is perceived to be a right, left or a reverse curve will all influence the decision of the motorcyclist.

Figure 4.11: Horizontal curve types and riding paths

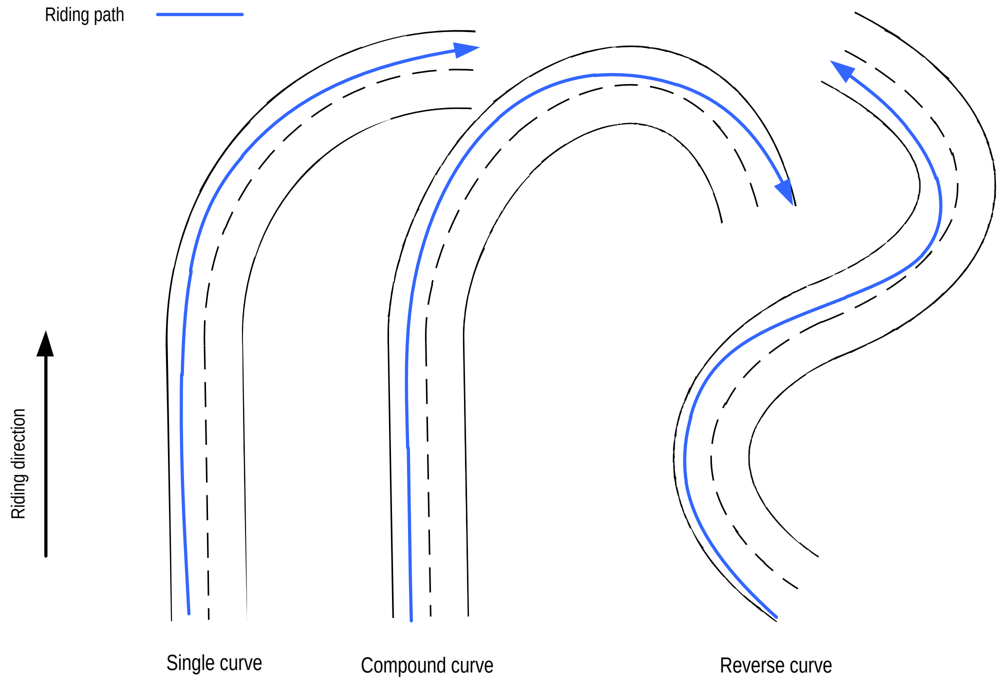
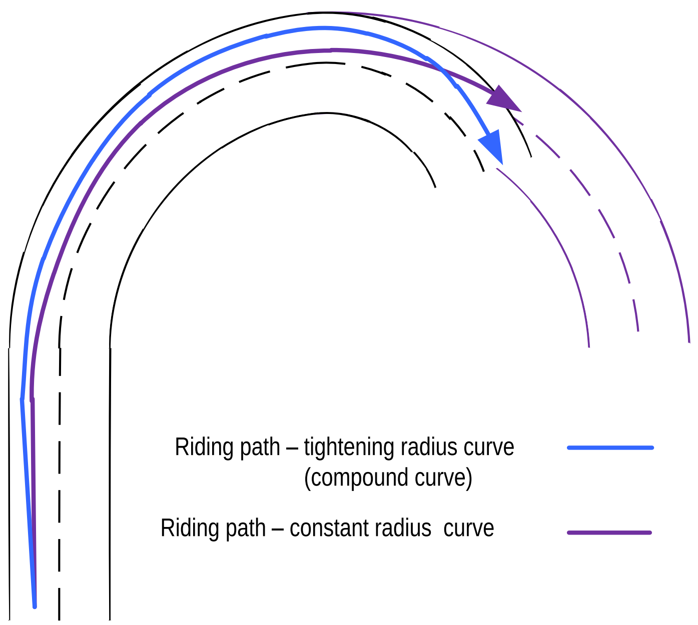


Figure 4.12: Compound curve riding paths



Note: If the presence of a compound curve is not known a motorcyclist will select a riding path for a constant radius curve and be required to change it using increased lean angles and braking.

Increased crash risk on horizontal curves

The risk of a motorcycle destabilising whilst on a curve is increased when braking (Figure 4.13) and/or sudden changes in riding paths occur (Figure 4.14). This can be due to a motorcyclist entering the curve at a higher then suitable speed, perhaps as a result of not being able to predict the road alignment. A curve that comes to a motorcyclist as a surprise as a result of poor sightlines or inadequate signage and delineation may result in braking/emergency braking or evasive action to avoid surface hazard or vehicle (from the opposing direction) which has crossed the centreline.

The surface texture or surface condition will also influence the likelihood of a loss of grip whilst undergoing braking/emergency braking or evasive action.

Figure 4.13: Motorcycle braking on curves

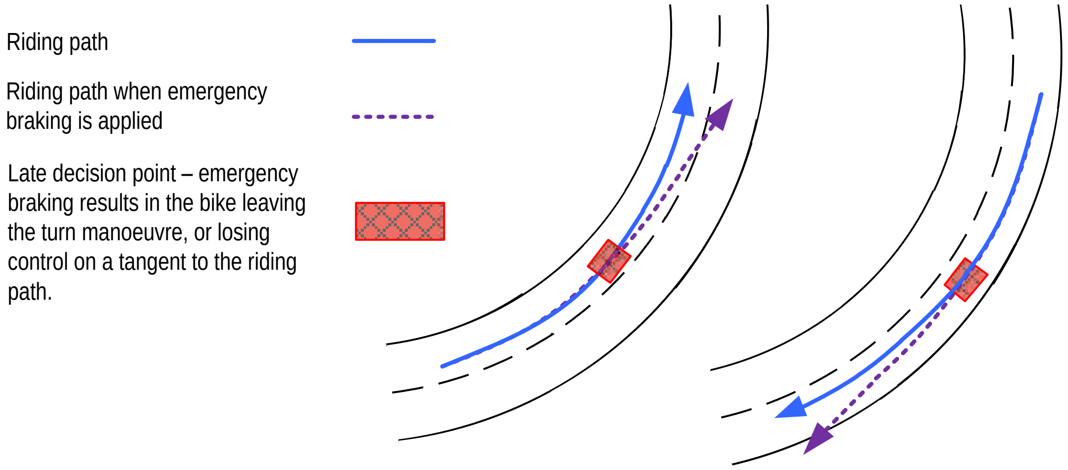
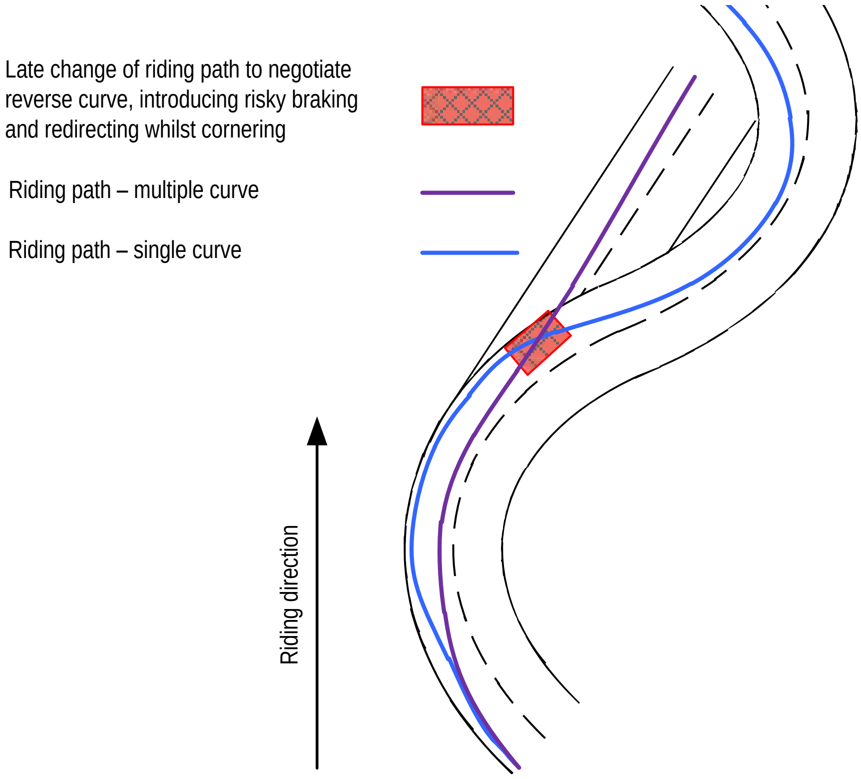


Figure 4.14: Unclear road alignment resulting in change of riding path



A road, or route, with a high number of curves inherently has a higher crash likelihood for all road user groups, however, motorcycles are most affected due to their unique handling characteristics.

A motorcycle-specific road safety audit undertaken by ARRB Group (Milling & McTiernan 2014) noted during site inspections that when negotiating a curve, motorcyclists recounted feeling most at risk to crashing due to poor surface friction (braking and remaining stable whilst the bike is leaning over) when negotiating curves. The report showed that of the 18 sites audited, over 50% of the total length consisted of horizontal curves. The curve types included compound curves, reverse curves and sharp curves. The most problematic curves were sharp curves in a series of larger curves, curves with narrow lane width, curves with restricted sight distance or a combination of all. A summary of curves as a percentage of the total length of the audited sites (Table 4.10) gives an indication of how the curve crash risk would be high on these roads.

Table 4.10: Road geometry, all audit sites – SA road safety audit report

Road geometry	Length (km)	Length as %
Left curve	50.5	17.0
Reverse curve	46.3	15.6
Right curve	48.5	16.3
Sharp right	1.8	0.6
Sharp reverse curve	0.9	0.3
Sharp left curve	2.5	0.8
Compound curve	2.3	0.8
Sharp compound curve	0.3	0.1
Straight	140.5	47.2
Intersections	3.9	1.3
Total	**297.5**	**100%**

Source: Milling and McTiernan (2014).

Vertical curves

A vertical curve will influence the likelihood of a crash are when:

- a crest restricts the sight distance and a surface hazard cannot be identified and safely avoided
- a crest restricts the sight distance to a property entrance or side road
- a steep down grade is combined with a curve. Heavy braking and turning would be required when this occurs.

4.4.2 Sight Distance

Sight distance enables a motorcyclist to identify and react to a hazard ahead in a safe and controlled manner. In recognition that the stopping distances of motorcycles are dependent on surface texture, surface condition, weather and motorcyclist experience, minimum sight distances should be available. Sight distance is used by a motorcyclist to:

- select a riding path appropriate to the curve type, length and direction to safely negotiate that change in the alignment
- identify changes in surface texture, surface hazards, surface condition and reduce speed to safely avoid and change the intended riding path
- identify a vehicle from the opposing lane that has crossed the centre line and safely reduce speed and take appropriate action in a controlled manner.

Where the sight distance is restricted due to a crest or horizontal curves with roadside vegetation (Figure 4.15), embankments (Figure 4.16), safety barriers or roadside furniture, a motorcyclist has less or possibly no time to react to select an appropriate riding path or course of evasive action.

Figure 4.15: Restricted horizontal sight distance on large radius curve

Source: Courtesy of ARRB Group and DPTI.

Figure 4.16: Restricted horizontal sight line on sharp curve with narrow sealed shoulders and adjacent aggressive rock face

Source: Courtesy of ARRB Group and DPTI.

It should be noted that on an undivided road, the sight line on a right hand curve is less likely to be restricted (Figure 4.20) unless a vehicle is in the opposing travel lane. This, however, is not the case for a divided carriageway or ramp where safety barriers (Figure 4.17), vegetation (Figure 4.18) or street furniture are on the right hand shoulder or central median.

Figure 4.17: Restricted sight lines – right hand curve on interchange ramp

Source: Courtesy of ARRB Group.

Figure 4.18: Restricted sight lines – right hand curve divided carriageway

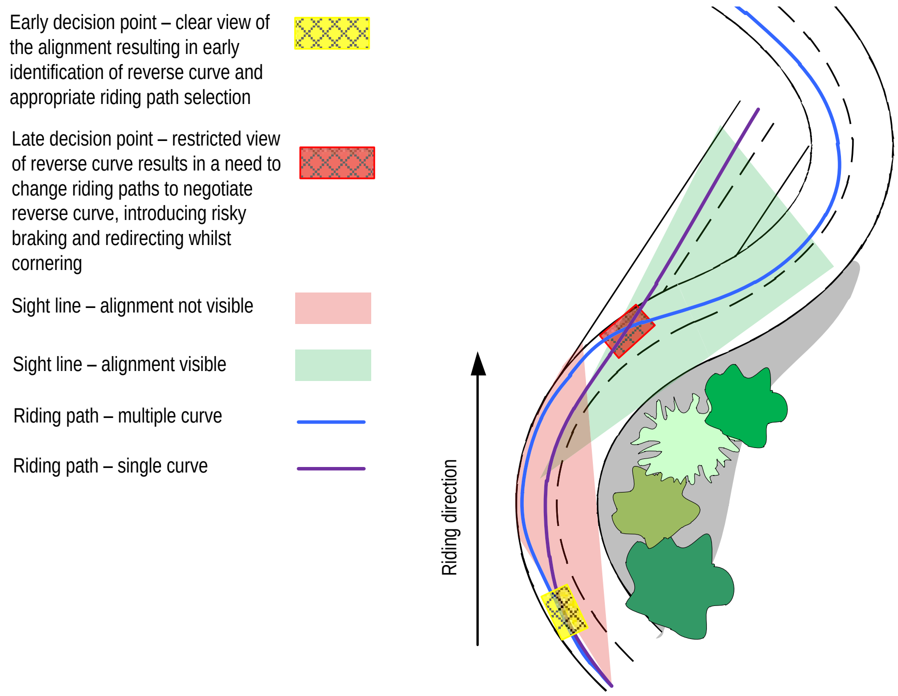
Source: Courtesy of ARRB Group and DPTI.

Sight distance effects on the riding path selected

A motorcyclist is reliant on clear sight lines to plan a safe riding path. Where a clear sight line is not available, a motorcyclist will have to rely almost extensively on warning signage and delineation. This is discussed further in Section 4.4.4. As shown in Figure 4.19, the riding path a motorcyclist would select for a single curve (i.e. outside lane cutting into the centre) is different from the path selected for a reverse curve (i.e. outside lane and crossing to the inside lane of the following curve).

If the motorcyclist selects a riding path for a single curve and a second successive curve is present that turns in the opposite direction (reverse curve) the motorcyclist will have to change the riding path to stay within the carriageway which introduces braking and changes in direction. This, in turn, results in the motorcycle rapidly switching leaning from one side to the other side and, when combined with braking, increases the risk of the motorcycle destabilising and losing control. The 'decision point' at which a motorcyclist is likely to have to change riding paths is shown by the red box in Figure 4.19. Sudden changes in riding path may lead to the motorcycle destabilising due to the increased demand on the motorcycle, the road surface texture and condition and the grip between the tyre and road surface.

Figure 4.19: Restricted sight lines – change of riding path



Sight distance effects on identifying road surface hazards and vehicles over the centre line

Due to objects, vegetation and cuttings, left hand curves are more susceptible to restricted sight lines, whereas a sight line on a right hand curve (dependent on curve radius) is generally less restricted (Figure 4.20). If a motorcyclist can clearly identify a hazard on the road (such as a change in surface texture, a surface defect or poor surface condition), he/she has the opportunity to change riding path and/or reduce speed to safely avoid that hazard (Figure 4.21).

Where the sight line is restricted, detection becomes impossible or too late to allow evasive action to be taken in a safe and controlled manner (Figure 4.22). Heavy braking and/or sudden changes in direction are then likely to be required to avoid the hazard or vehicle. Alternatively, a motorcyclist may elect to or have no other option but to 'ride over' the hazard. This increases the crash likelihood by:

- taking evasive action
  - destabilisation due to the increased demand on the motorcycle and road surface texture when taking evasive action
  - change in riding path, entering into head-on zone or crossing the centreline into the opposing lane
  - change of riding path enters into the shoulder
- 'riding over' the hazard
  - destabilisation due to direct impact or loss of friction
  - redirection into head-on zone or crossing the centreline into the opposing lane
  - redirection into the shoulder.

Figure 4.20: Right hand curves are less susceptible to restricted sight lines

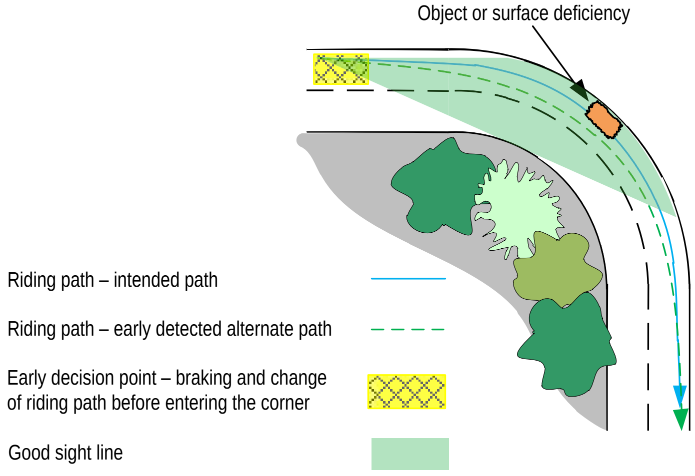
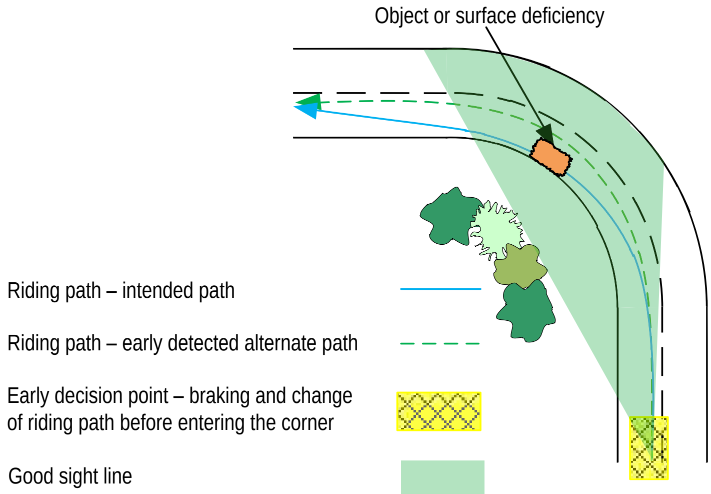
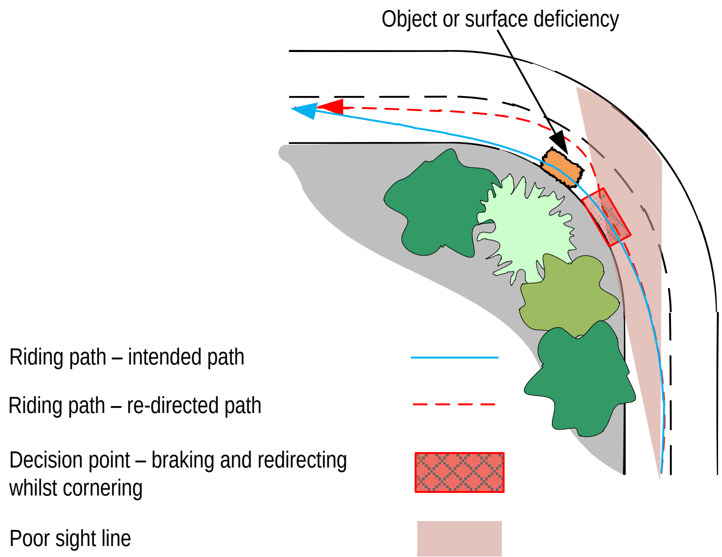


Figure 4.21: Open sight lines – early identification of hazard on a left hand curve



Note: This is also applicable to a straight section of road with a good sight line on a crest or sag.

Figure 4.22: Restricted sight lines – late identification of hazard on a left hand curve



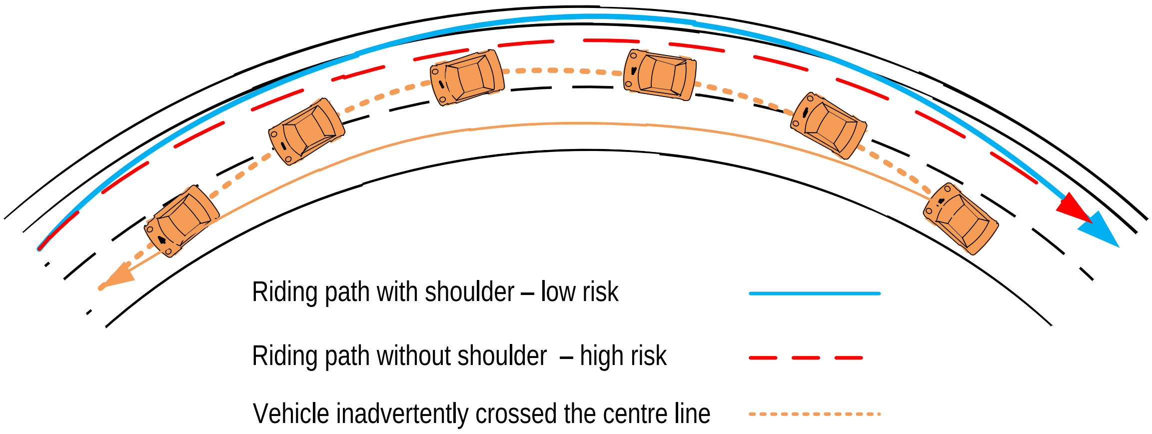
Note: This is also applicable to a straight section of road with a restricted sight line due to a crest or sag.

4.4.3 Carriageway Width

Both lane and shoulder widths are important for motorcyclists as they provide width to negotiate the alignment safely, avoid surface hazards and stay clear of the shoulder, head-on zone or vehicles that have crossed the centreline or emerge from the shoulder. Crash likelihood is increased as the lane width and shoulder width decreases.

A combination of no shoulder and narrow lanes will result in a motorcyclist selecting a riding path near to the head-on zone on right hand curves and near to roadside hazards on the shoulder on left hand curves. If the lane width is narrow, a usable sealed shoulder will allow evasive action. An example is provided in Figure 4.23.

Figure 4.23: Carriageway width – motorcycle and vehicle interaction



Note: This scenario is also applicable on straights, particularly on crests.

Lane width

Lane width has an influence on how close the riding path and, therefore, motorcyclist is to the head-on zone or the edge of the lane and any roadside hazards or the edge of formation (Figure 4.24).

The width of the head-on zone does not decrease. As the width of the head-on zone does not decrease, the relationship between head-on crash risk and lane width is simple – as the lane width decreases a motorcyclist will be closer to the head-on zone and, therefore, the crash likelihood increases.

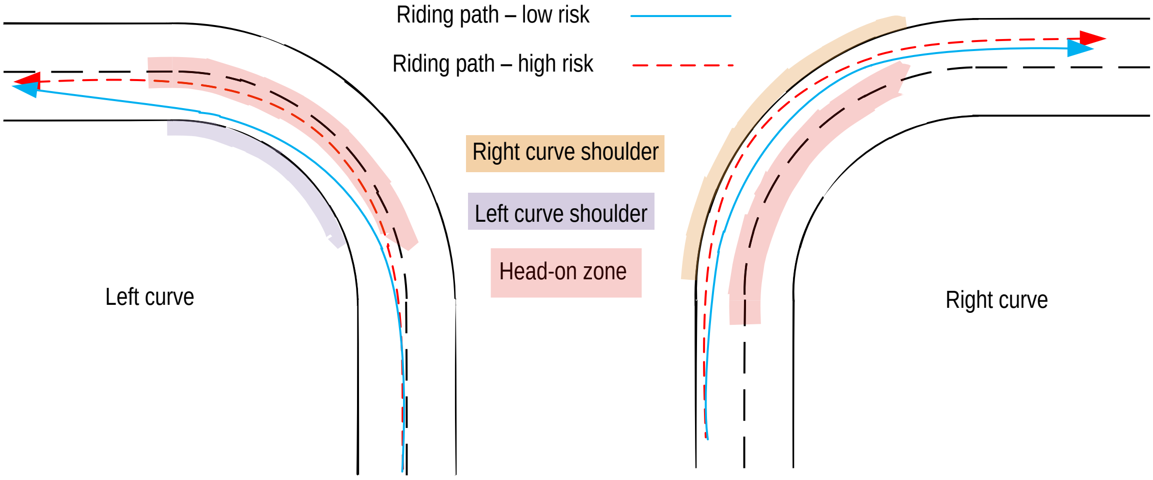
Lane width has a greater influence on crash likelihood on a curve. The smaller the curve radius, the more a motorcycle is required to lean on a curve, resulting in the motorcyclist's upper body leaning over the centreline or edge line.

Some examples of the effects of lane width are as follows:

- enables a motorcyclist to select a safe riding path away from the shoulder and head-on zone, particularly on curves (Figure 4.25)
- provides a buffer to the head-on zone and vehicles in the opposing lane
- provides width for a motorcyclist to avoid surface hazards and vehicles (crossing the centreline or entering from a driveway) without entering the shoulder, the head-on zone or the opposing lane (Figure 4.26)
- provides a buffer to parked cars, reversing onto the carriageway and opening car doors (Figure 4.26).

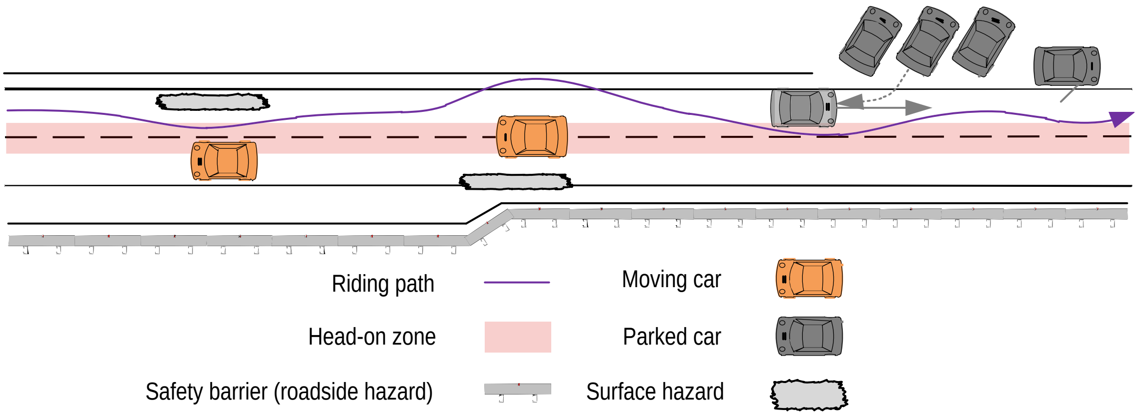
Figure 4.24: Narrow lane and shoulder width

Figure 4.25: Carriageway width and riding paths



Note: This scenario is also applicable on straights, particularly on crests.

Figure 4.26: Carriageway width – motorcycle, vehicle and surface hazard interaction



Note: This scenario on a curve or crest has a higher crash likelihood.

Shoulder width

Some examples of the positive effects of the presence or width of a road shoulder are as follows:

- provides an area clear of the lane for a motorcycle to stop in an emergency/breakdown
- improves sight lines through curves
- provides a buffer to kerbs, roadside hazards (including roadside furniture) and embankments (Figure 4.27)
- provides an additional width for an errant motorcycle to:
  - change a riding path to avoid a hazard or vehicle
  - reduce speed before impacting a roadside object and losing control or hitting a vehicle (Section 4.6.1)
- provides width for a motorcyclist to safely avoid surface hazards
- provides width for a motorcyclist to avoid vehicles that have crossed the centreline (Figure 4.26).

Figure 4.27: Road furniture on the inside of a turn

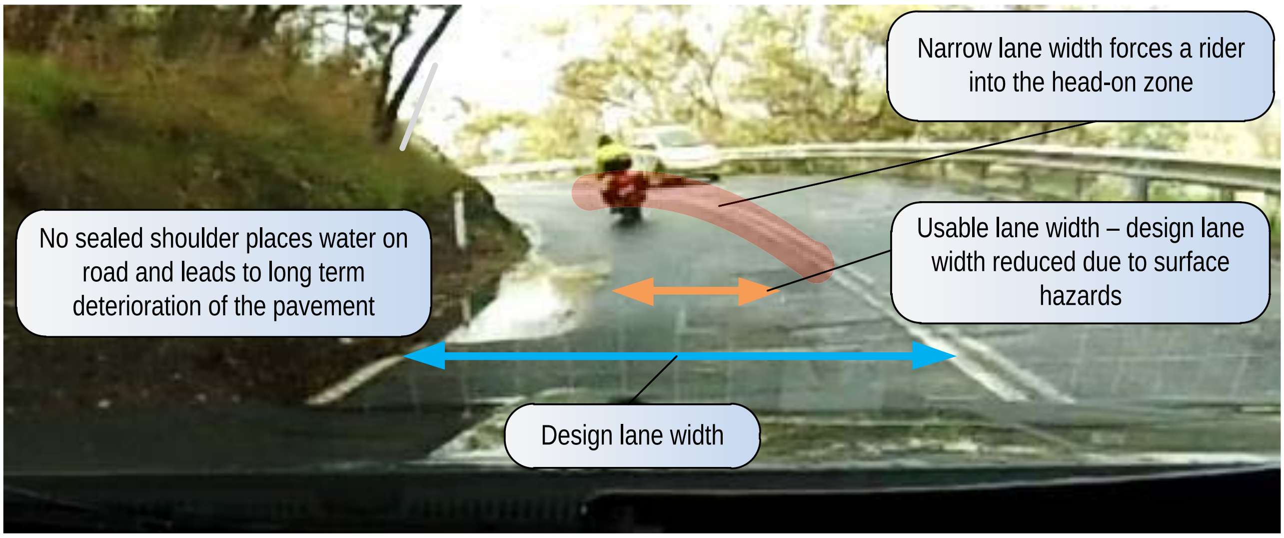
Source: Motorcycle Safety Advisory Council (2014).

Design width and usable width

The designed/trafficable lane and shoulder width may reduce periodically due to the presence of a surface hazard (Figure 4.28) such as a pothole, service cover or water on the road (explained further in Section 4.4.6). Often when a sealed shoulder is not present, the left side of the travel lane is susceptible to material from the shoulder entering the lane, debris build up against a kerb, pavement deformation, edge drop and water not draining due to an uneven pavement surface.

The usable lane or shoulder width for a motorcycle is the width that is hazard free which in some cases may be 50% of the designed/trafficable lane width. The usable lane width will affect the line of a riding path resulting in a higher risk riding path closer to the shoulder or head-on zone as shown in Figure 4.25.

Figure 4.28: Reduced carriageway width pushing motorcycle into head-on zone



4.4.4 Delineation and Signage

Delineation and signage of the carriageway geometry/layout and any associated hazards provide important information to allow a motorcyclist to make safe and informed decisions about travel speed and riding path selection. Having adequate time to make decisions reduces the need for heavy braking and evasive manoeuvres which increase the likelihood of a crash.

The consistency of delineation and signage (in both type and positioning/placement) on a road and surrounding roads (often referred to as 'similar' or 'like' sites) is important. A motorcyclist will use cues from the presence of delineation and signage to make decisions as they ride. When provided over a length of road, there is an expectation that these will consistently develop. If the cues are no longer provided or provided in a different way, the motorcyclist has to react accordingly and may need to take evasive action given that they may have not already changed their riding behaviour. Some examples where a motorcyclist relies on the presence of delineation and signage are as follows:

- on a tight horizontal or vertical alignment with restricted sight lines
- on a road where intersections are infrequent and are not conspicuous
- where a road seal reduces from two opposing lanes to a single (centrally located) sealed lane with unsealed shoulders
- where two lanes reduce to one lane or at the end of a merge.

The condition and clarity of delineation and signage is also imperative so as a motorcyclist is able to absorb the information being conveyed. Assuming that the minimum amount of delineation and signage required by best practice principles is provided, it will only be effective if it is maintained in good condition. Some common reasons for delineation and signage not performing as intended are as follows:

- delineation:
  - linemarking is faded
  - linemarking is covered by grass, gravel from the shoulder, leaves from adjoining trees or is lost due to edge break
  - raised reflective pavement markers (RRPMs) are faded or missing.
- signage:
  - faded and not conspicuous
  - covered by vegetation, guardrail or other signs
  - blends into the surrounding environment (vegetation, landscape or advertising signage)

  - lost reflectivity and is not visible at night
  - reflectivity is too bright or the installation angle is correct and reflected light temporarily blinds motorcyclist.

Defining the alignment

Delineation is often considered for its importance in advising road users of an alignment at night, particularly on roads that do not have street lighting. It has been found, however, that motorcyclists also rely heavily on delineation during the day.

When considering night time visibility, it is important to note that motorcycles have a limited head light range, particularly whilst turning or leaning on a curve. In some circumstances, it is not unusual for a motorcyclist to rely on delineation alone to identify the alignment of the road at night time.

In summary, examples of the positive role of line marking, RRPMs and guide posts for motorcycles are as follows:

- defines the alignment, namely curves and crests
- defines the edge of the lane or formation where there is no shoulder
- provides a vanishing point on straights and curves
- defines the lane and carriageway width
- defines lane assignment, namely in urban areas and on low-volume narrow rural roads.

Warning, hazard and information signage

Warning, hazard and information signs provide all road users with information in advance. With respect to motorcycles, this enables a motorcyclist to reduce their speed and change their riding path without the need to take evasive action. Some signs include advance intersection direction, intersection ahead warning, road condition warning and hazard warning signs.

The presence of clear signage reduces crash likelihood by allowing a motorcyclist to:

- progressively reduce to a suitable speed to:
  - stop before a potential conflict with a pedestrian, vehicle or hazard
  - traverse a section of pavement that is in poor condition
  - change lanes to make a turn or enter a commercial or residential access
  - negotiate a sharp curve, compound curve or reverse curve
- change the riding path without using evasive action to:
  - avoid a surface hazard (road grooving, rutting or loose aggregate)
  - stay clear of a roadside hazard (culvert (Figure 4.29), tree (Figure 4.30), drainage ditch (Figure 4.31) or utility pole)
  - not enter the shoulder where a hazard is present
  - negotiate a left, right, reverse or compound curve
  - merge or change lanes to take an exit or when a lane ends (lanes drop).

A motorcycle specific road safety audit undertaken by ARRB Group (Milling & McTiernan 2014) noted during site inspections that motorcyclist undertaking the audit was not able to identify clearly the road alignment or upcoming features or hazards when linemarking was faded or not present and signage was not installed correctly, had faded and was inconsistent, missing and/or not visible on approach. Of the 18 sites audited, over 20% of the total length had signage and delineation deficiencies. A summary of the deficiencies is shown by road geometry in Table 4.11. Almost half of the deficiencies occurred on curves affecting curve quality (Section 4.4.5).

Figure 4.29: Hazard sign on perpendicular culvert

Note: This could also be delineated with reflective paint.
Source: Courtesy of ARRB Group and DPTI.

Figure 4.30: Hazard sign on trees in shoulder

Source: Courtesy of ARRB Group and DPTI.

Figure 4.31: Hazard sign on drainage ditch

Note: A more specific warning sign would better describe the hazard, however, a hazard marker is a start.
Source: Courtesy of ARRB Group and DPTI.

Table 4.11: Signage and delineation deficiency examples

Road geometry	Poor signage and delineation	Length (km)	% of road
Straight	Missing intersection warning sign	0.5	0.2
	Linemarking faded	0.7	0.2
	Missing guide posts	5.1	1.7
	Inadequate number of guide posts	6.0	2.0
	Linemarking obscured by veg/debris	8.5	2.9
	Linemarking missing	19.0	6.4
	Straight total	39.8	13.4
Curve	Curve warning sign too low	0.1	0.0
	Curve warning sign poor condition	0.3	0.1
	Misleading curve warning sign	0.5	0.2
	CAMs incorrectly spaced	1	0.3
	Curve warning sign missing	1.2	0.4
	Curve warning sign obscured	1.3	0.4
	Insufficient no. of CAMs	1.5	0.5
	Hazard markers used as cams	1.9	0.6
	First CAM not visible from approach	2.1	0.7
	CAMs not visible from approach	4.2	1.4
	CAMs mounted too low	6.6	2.2
	No CAMs on curve	9.6	3.2
	Curve total	**30.3**	**10.2**
	Grand total	**70.1**	**23.4**

Note: The total length is the sum of the forward and reverse direction (i.e. twice the route centreline length).
Source: Milling and McTiernan (2014).

Vanishing point

A vanishing point is often defined as 'a point in the distance on which a road user focuses'. A simple 'where you look is where you go' principle applies i.e. a motorcycle, for instance, will ultimately travel in the direction of the motorcyclist's single focal point which is typically an object the motorcyclist is fixated on.

A vanishing point can be provided by guide posts, CAMs or linemarking, etc. ensuring that a focal point in view of the motorcyclist is consistent with the direction of the road alignment, thus reducing the risk of a motorcyclist being distracted by other objects on the roadside, such as trees or culverts, and leaving the roadway or crossing the centreline into the opposing lane. Whilst negotiating a curve, a motorcyclist will also be scanning the road surface to identify surface texture and any surface hazards. Some examples of how motorcyclists use delineation are as follows:

- **Sharp to very sharp curve** – a motorcyclist will use curve warning signs on the approach and CAMs visible from the approach to determine the curve direction, radius and, if possible, the length of the curve. This enables a motorcyclist to select an appropriate riding path and speed. Once a motorcyclist is leaning into the curve, the motorcyclist's view becomes restricted and he/she will preferably focus on the linemarking or guide posts to complete their riding path on that curve. When a motorcycle is leaning through a curve, the motorcycle's headlight is unlikely to strike any CAMs, however they will be visible on the curve approach whilst the motorcycle is upright.
- **Moderate curve over crest** – a motorcyclist will use curve warning signs on the approach and CAMs visible from the approach to determine the curve direction and radius. This enables a motorcyclist to select an appropriate riding path and speed. A motorcyclist will still lean into the curve, albeit being more upright than for a sharp or very sharp curve, so that their view will not be as restricted. Again, the motorcyclist will most likely focus on the CAMs and guide posts to complete the riding path on the curve.

- **Moderate curve** – a motorcyclist will use the guide posts both on the approach and on the curve to determine the curve direction and radius. This enables a motorcyclist to select an appropriate riding path and speed. As above, the motorcyclist will lean into the curve but remain in a more upright position to keep their view 'open'. The motorcyclist will then focus on the guide posts to complete their path on the curve.

Examples of misleading and good vanishing points are shown in Figure 4.32 and Figure 4.33, respectively.

Figure 4.32: Vanishing point – misleading and not consistent with the alignment

CAMs not present, vanishing point created by guide posts is misleading, particularly at night.

Vanishing point does not continue around curve and leads onto side road.

Source: Courtesy of ARRB Group and TMR.

Figure 4.33: Vanishing point – a good example, curve over crest

Source: Courtesy of ARRB Group and TMR.

4.4.5 Curve Quality

A sharp to very sharp horizontal curve presents risks to all road users, especially motorcyclists. The likelihood of a crash can be reduced by clearly defining the direction of the curve, how sharp the curve is and the curve type (single, compound or reverse) using delineation. The clarity of the curve provided by signage and delineation is known as the 'curve quality'.

Curve quality allows motorcyclists to make safe and informed decisions to negotiate safely a change in the alignment. This includes:

- identifying the presence of the curve
- the curve type, direction and length
- selecting a riding speed for the curve
- selecting a riding path appropriate to the curve type, length and direction.

Having adequate time to assimilate the layout and make appropriate decisions reduces the need for heavy braking and evasive manoeuvres, both of which increase the likelihood of a crash. This is particularly important on sharp to very sharp curves as the likelihood of a motorcycle destabilising is higher due to its handling characteristics. This likelihood is increased if sudden changes in riding path or emergency braking are required as a result of misreading the curve direction, radius or curve type.

Curve warning signs

Curve warning signs convey information about a curve's presence, radius and direction to the motorist. This is used by motorcyclists to adjust their approach speed, select a riding path and anticipate a riding speed for the curve.

Curve warning signs should be:

- conspicuous and clearly visible at a distance. A larger sign size or special curve warning sign (Figure 4.34) may be advantageous in some situations
- placed far enough in advance of the curve for a motorcyclist to have adequate time to react (Consideration should be given to the effects of a combination of the current or likely surface conditions after wear and tear and motorcycle braking on the co-efficient of deceleration)
- accurate i.e. reflect the curve type and radius (Figure 4.41)
- installed clear of vegetation that is likely to grow over the sign face.

Compound curves (tightening curves) will require special warning signs as a curve and turn warning sign do not indicate a compound curve. A supplementary plate will indicate a compound curve (Figure 4.35). A compound curve where the approach speeds may be high should have special signage (Figure 4.36).

Caution should be used where successive curves are present. A series of curves may consist of compound curves and curves that are tighter than others. This information may be lost through the use of a winding road curve warning sign. An example of where a winding road curve warning sign results in the presence of a tight compound curve not being clearly identified with signage is shown in Figure 4.37.

Figure 4.34: Special curve warning sign example

Source: TMR TC Sign TC9759 (special warning curve sign).

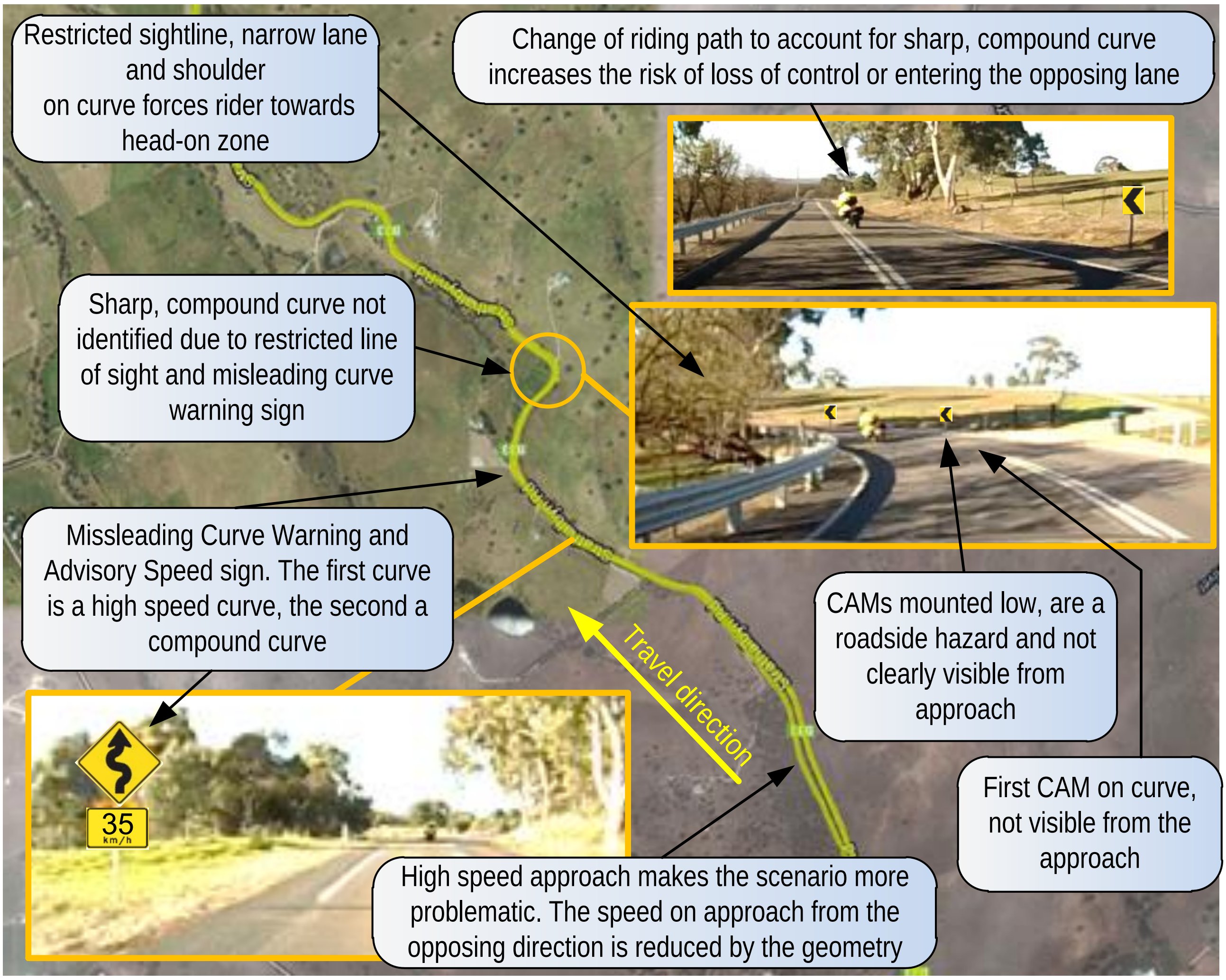
Figure 4.35: Compound curve warning signage

Source: TMR TC sign TC1777 (supplementary plate 'curve tightens').

Figure 4.36: Compound curve warning sign with flashing lights

Note: Example of TMR TC sign TC1777 and warning signs with flashing lights (AS 1742.2–2009, Appendix E).

Figure 4.37: Curve warning and CAMs not being used effectively



Notes:
CAMs have been digitally overlaid on images as they blended into the grass on the hills in the images.
The winding road sign is digitally overlayed to clarify the sign type and advisory speed.

Chevron alignment markers

Chevron alignment markers (CAMs) indicate the start of a curve to a motorcyclist, and confirm the direction of a curve. CAM's lead the motorcyclist through the curve. Three CAMs should always be visible, this is in accordance with Australian Standard AS 1742.2-2009 *Manual of Uniform Traffic Control Devices*, and indicate the length or delineate the continuation of the curve. As a CAM is different in colour and has a directional arrow on the sign face, the use of a CAM to delineate a curve as opposed to alternatives such as plastic poles (Figure 4.38) or closely spaced guide posts (without CAMs) more clearly defines the curve. The presence of clearly visible CAMs reduces crash likelihood as:

- They indicate the presence of a curve from the approach (important if the curve warning sign is not conspicuous or is missing).
- The CAMs directional arrows show the direction of the curve (Figure 4.39), particularly at night (Figure 4.40) from the approach only but not when the bike is leaning due to a loss of headlight performance (refer Section 4.5.7 and Figure 4.94).
- They give an indication of the curve radius from the approach and throughout the curve allowing a rider to enter the curve at an appropriate speed.

Figure 4.38: Flexible bollards do not indicate direction of the curve from the approach

Source: FEMA (2012).

Figure 4.39: Curve warning sign and CAMs confirming direction of the first curve in this series of curves

Source: Courtesy of ARRB Group and TMR.

Figure 4.40: Curve quality at night, guide posts at closer spacing on a reverse curve

Source: Courtesy of ARRB Group.

The effectiveness of CAMs, however, is determined by their appropriate usage and local installation and maintenance practices. When using CAMs, principles which have a positive influence on motorcycle crash likelihood are as follows:

- CAMs should be placed consistently on a road, surrounding roads or a route.
- CAMs should be placed on all sharp to very sharp curves, particularly those with curve warning signs and advisory speed signs (Figure 4.41).
- The first CAM should be visible from the approach and should be mounted so as they are visible from the approach (including over rises/crests).
- CAMs should be continual through the curve and there should be a minimum of three CAMs visible at all times.
- CAMs should not blend into the surrounding vista (e.g. vegetation, advertising signage and grassy fields with browning grass as shown in Figure 4.42 and Figure 4.43), in which case larger sign faces or a special CAM with a coloured border may be beneficial (Figure 4.44).
- The correct sign face (D4-6) should be used and not hazard boards and arrows (Figure 4.45).
- They should be installed clear of vegetation that is likely to grow over the sign face.
- Additional CAMs (more closely spaced) provide an advantage, however, they should be motorcycle friendly so as not to increase crash severity by introducing more roadside objects.

Figure 4.41: CAMs not provided on reverse compound curve with sharp curve warning and speed advisory plate

Reverse curve warning sign provided on compound curve *No CAMs provided on curve – No horizontal sight distance*

Source: Courtesy of ARRB Group and DPTI.

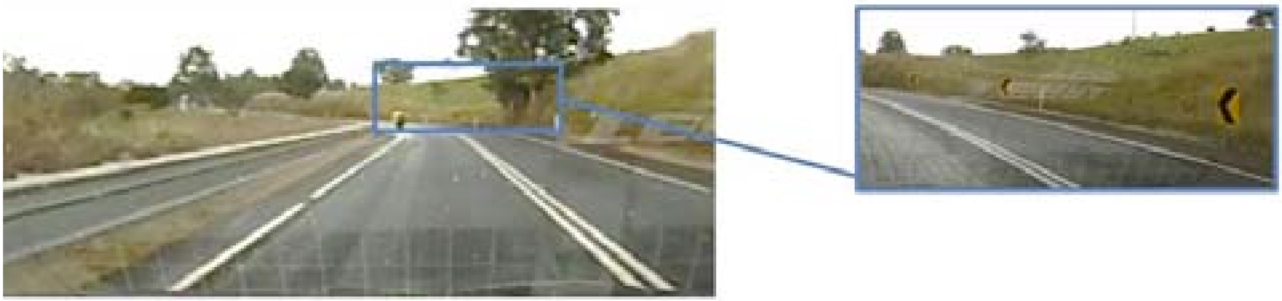
Figure 4.42: CAMs blending into background and hidden by guard rail

CAMs poorly positioned, not conspicuous

CAMs mounted too low, restricted by CAMs for opposing direction

Source: Courtesy of ARRB Group and DPTI.

Figure 4.43: CAMs blending into background



CAMs not conspicuous, blended into background colours and mounted too low.
Source: Courtesy of ARRB Group and DPTI.

Figure 4.44: Conceptual high visibility CAM

Figure 4.45: CAMs not conspicuous and hazard markers used

Hazard markers used as CAMs. Hazard markers not conspicuous and are blended into background colours and mounted too low.
Source: Courtesy of ARRB Group and DPTI.

Guide posts, linemarking and RRPMs

The presence, positioning and condition of guideposts, linemarking and RRPMs on a curve is important for all road users. Motorcyclists are reliant on such items, particularly at night, and use a combination of all three to look through the curve (to detect a vanishing point) and negotiate it safely.

Guide posts provided at a closer spacing (more than two visible at a time) on a straight where the alignment is undulating will improve delineation of the road alignment by providing a continual vanishing point. Providing additional guide posts on a curve (more than recommended for that curve radius) will have an ever greater benefit during both the day and night (Figure 4.40). Providing guide posts at closer spacing may also reduce the speed environment and in turn the motorcyclist's operating speed and likelihood of a crash.

Positive influences which linemarking and RRPMs have on the likelihood of motorcycle crash risk are as follows:

- Centreline and edge lines define the alignment, particularly at night (Figure 4.40).
- A centre line, particularly on low-volume rural roads, will define the lane separation which in turn allows a motorcyclist to select a riding path away from the head-on zone.
- Edge lines allow a motorcyclist to more easily select a riding path away from the shoulder.
- The presence of a centre line and edge line allow a rider to select a riding path away from the head-on zone and the shoulder.
- RRPMs delineate the alignment at night (Figure 4.40) and enhance the delineation provided by linemarking giving the motorcyclist an indication of the lane width and centreline and edge line locations from the curve approach.

4.4.6 Road Surface

A motorcycle is reliant on a smooth, debris-, hazard- and object-free surface with adequate and consistent surface texture (including skid resistance) whilst turning, cornering and braking (Section 4.1). A motorcycle is most reliant on the road surface when turning, on a curve, applying emergency braking, undertaking evasive manoeuvres or, re-directive manoeuvres or a combination of all three. The road surface includes the through lane and the shoulder.

The crash likelihood is increased when:

- surface texture (including skid resistance) is inadequate by design, or because of wear and tear, pavement marking or steel plates, particularly in wet weather
- surface condition has deteriorated and hazards such as ruts and potholes are present
- surface objects such as service covers or tram lines are present from design
- debris lies on the road surface (e.g. gravel from the shoulder, driveways or fallen leaves from adjacent vegetation).

As a motorcycle is required to lean when turning or negotiating curves, a higher reliance on the road surface is required and this reliance increases:

- as the radius decreases (the lean angle increases, Section 4.1)
- as curve riding speed increases (the lean angle increases, Section 4.1)
- if emergency braking or evasive action is required (front wheel steer angle contradicts the forward momentum of the motorcycle (Section 4.1)).

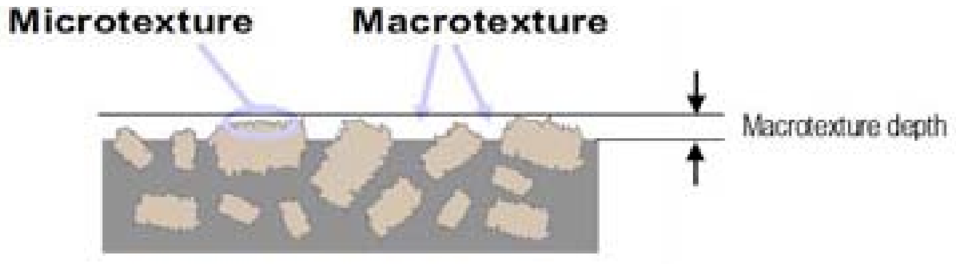
Surface friction ('grip')

A consistently appropriate level of surface friction ('grip') is required for a motorcyclist to remain stable during accelerating, braking, turning, cornering and whilst redirecting a riding path or taking evasive action. It is important to note that this is true in both dry and wet conditions, although the availability of 'grip' becomes highly significant in wet conditions.

When considering the road surface alone, the level of 'grip' is often related to 'skid resistance', however surface friction also affects the 'side friction' demand on a vehicle/motorcycle when in curves, this is known as the co-efficient of side friction. Surface friction and therefore skid resistance, and the co-efficient of side friction is comprised of two components – microtexture and macrotexture (Figure 4.46).

Microtexture is provided by the surface of aggregate on the road surface and macrotexture by the shape of and space between the aggregate particles. Microtexture provides adhesion at the direct interface between the road surface and tyre and is predominant at lower traffic speeds, after which its role diminishes. Macrotexture (sometimes referred to as texture depth) has a greater effect at higher vehicle speeds, as well as providing voids to disperse water between the road surface and tyre to prevent aquaplaning.

Figure 4.46: Diagrammatic representation of road surface microtexture and macrotexture



Source: Austroads (2009b).

Some examples of how or where the level of 'grip' affects the likelihood of a motorcycle crash are as follows:

- on curves and turns (co-efficient of side friction), particularly when braking and the appropriate lean angle is greater (refer Section 4.1)
- stopping distances (skid resistance and the rate of deceleration):
  - the likelihood of the front or rear wheel sliding out due to inadequate or inconsistent/changing surface texture
  - the interpreted skid resistance by pavement types (asphalt/chip seal) will affect the braking force applied and in turn the total stopping distance (a motorcyclist may perceive that the same surface has a lower skid resistance when wet (predominantly asphalt))
  - the visual condition (polishing, flushing, bleeding, ravelling and stripping)
  - the condition of aggregate and resulting surface microtexture and macrotexture depth
- tyre slip (the motorcycle sliding):
  - changing wearing surfaces (e.g. bitumen seal/asphalt) may result in changes in the level of 'grip' and, therefore, may result in slip of the motorcycle tyres, particularly on curves and during braking (Figure 4.47)
- intersection approaches and turns:
  - braking (including heavy braking) on intersection approaches
  - combinations of braking and leaning whilst turning through an intersection
- evasive action:
  - when a motorcycle changes direction suddenly and brakes
  - all of the above when the road surface is wet.

Figure 4.47: Changing road surface on compound curve

Note: Compound curves require multiple riding paths, corrections and heavy braking and re-directive manoeuvres if a motorcyclist is required to change a riding path as a result of not identifying that the curve tightens.
Source: ©nearmap (2015), 'SA', map data, nearmap, Sydney, NSW.

Surface friction should be consistent and predictable to decrease the likelihood of crashes. Surface texture can vary along a road or route due to different wearing courses, painted surfaces (pavement arrows, pedestrian crossings, entry statements, 40 km/h school zone markings etc.) or a reduction in surface texture due to wear and tear or contamination from debris (oil, gravel etc.), such situations should be avoided by practitioners. A change of 'grip' on the wearing course or loss of 'grip' due to paint or debris may cause a motorcycle to loose traction and become unstable.

Some examples where the level of 'grip' can be adversely reduced or changes in 'grip' can occur are as follows:

- deterioration of the wearing course:
  - polishing of aggregate
  - flushing and bleeding (Figure 4.48)
  - abrasion, ravelling and stripping (Figure 4.49)
  - crack sealant (Figure 4.50)
- change of wearing course:
  - asphalt overlays, particularly on curves (Figure 4.47), intersection approaches and through the intersection and on turning treatments
  - pavers used as wearing course:
    - LATM treatment
    - entry statements/painted surfaces (Figure 4.51)
    - low speed and shared zones/beautification (Figure 4.52)
- pavement markings:
  - local area traffic management treatments (LATM) and entry statements
  - pavement arrows
  - pedestrian crossing markings (Figure 4.53)
- foreign matter:
  - gravel (from driveways, shoulders, new spray seals or vehicle tyres) (Figure 4.54 and Figure 4.55)
  - plant matter (Figure 4.56)
  - oil and fuel
  - frost
  - moss

- low texture surfaces:
  - bridge joins (Figure 4.57 and Figure 4.58)
  - train and tram tracks
  - service covers
  - raised pavement markers
  - timber (bridges)
  - temporary kerbs and speed humps (plastic or rubber)
- roadworks:
  - temporary pavements
  - temporary kerbs and speed humps (plastic or rubber)
  - milled surfaces (asphalt works) (Figure 4.59)
  - steel plates over excavations (Figure 4.60).

The microtexture and macrotexture properties of all wearing courses and painted surfaces should be carefully considered, particularly on braking and turning zones and on curves. Road surfaces should also be maintained to ensure they are free of foreign matter and adequate surface friction is available. The effectiveness of road drainage features should similarly be maintained.

Figure 4.48: Bitumen flushing in the wheel paths

Source: Courtesy of ARRB Group and CRRS.

Figure 4.49: Aggregate stripping on curve

Source: Courtesy of ARRB Group and DPTI.

Figure 4.50: Excessive amount of crack sealant

Source: Google Maps (2016), 'Queensland', map data, Google, California, USA.

Figure 4.51: Painted pavers and pavement marking in braking and turning zone

Source: Courtesy of ARRB Group.

Figure 4.52: Pavers and pavement markings, city beautification/shared zone

Source: Google Maps (2016), 'South Australia', map data, Google, California, USA.

Figure 4.53: Pedestrian crossing pavement marking in braking zone

Source: Courtesy of ARRB Group.

Figure 4.54: Debris on road from unsealed side road

Source: Courtesy of ARRB Group and DPTI.

Figure 4.55: Debris from shoulder on curve

Source: Courtesy of ARRB Group and DPTI.

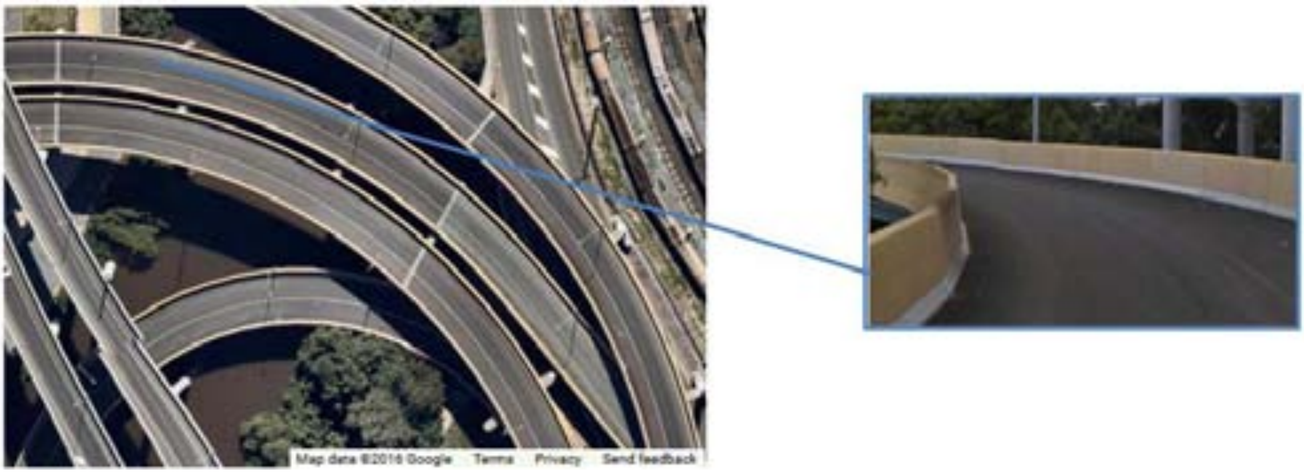
Figure 4.56: Plant debris

Source: Courtesy of ARRB Group and DPTI.

Figure 4.57: Bridge join on a curve

Source: Google Maps (2016), 'New South Wales', map data, Google, California, USA.

Figure 4.58: Multiple bridge joins on a curve with restricted sight lines



Source: Google Maps (2016), 'Queensland', map data, Google, California, USA.

Figure 4.59: Road works, milled surface with gravel spill from asphalt works in through lane and right turn lane

Source: Courtesy of ARRB Group.

Figure 4.60: Steel plates over trenches

Source: VicRoads (2014).

Surface drainage

It is widely found that water on the road surface can routinely reduce the skid resistance available by between 20 and 30%, which in turn reduces stopping distances and side-friction. Water on the road surface is also seen as a hazard and is avoided by motorcyclists as the condition of the road under the pooling water is not known and water on a tyre affects the handling of the motorcycle. Water on the road surface is particularly hazardous on roads and routes that are frequented by motorcyclists as a motorcyclist may not anticipate a change or the degree to which the grip changes due to the wet surface or water on a tyre.

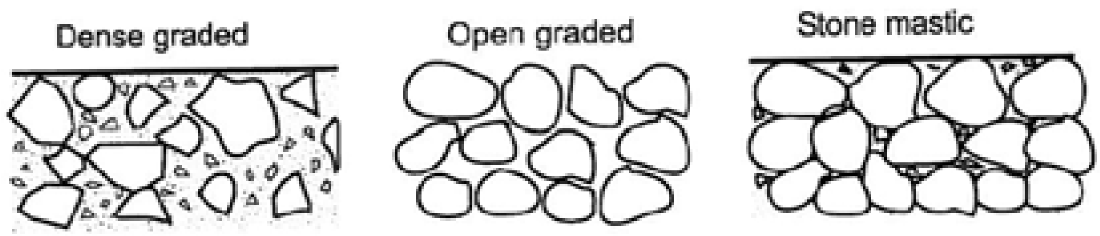
Water on the surface can be a result of:

- poor drainage design at intersections and on the midblock (superelevation transition points, wide pavements and long grades)
- depressions or rutting preventing water from draining
- water sitting in service covers that are lower than the pavement surface
- water from the shoulder entering the through lane (rural areas with no formal drainage, seepage from cuttings or in urban areas with narrow shoulder widths)
- water from properties adjacent to the road
- water from sprinkler systems (roadside landscaping) adjacent to the road, e.g. roundabouts
- water trapped in construction joints or trench repairs that have sunken below the surrounding road surface.

Some examples of how surface water affects motorcycle crash likelihood are as follows:

- tyre spray in the air and on a helmet visor restricting vision
- the water is identified as a hazard to avoid, resulting in a change of riding path or evasive action
- reduces friction between the surface and tyres affecting motorcycle stability when braking and cornering
- aquaplaning on:
  - a sprayed seal surface where the aquaplaning risk is dependent on the seal type/design, the aggregate size (chip seal) and resulting texture depth (Table 4.12)
  - an asphalt surface where the aquaplaning risk is dependent on the surface texture depth and the water flow below the surface of a pavement (water flow) as follows:
    - Asphalt typically has low texture depths (Table 4.12).
    - Open graded asphalt is the only asphalt where water flow removes some water from the surface (this is a result of the voids between the aggregate as shown in Figure 4.61).
    - Water flow rates are dependent on the construction and compaction of the pavement.
    - Water flow is considered to reduce over time due to compaction and build-up of debris in the asphalt.

Figure 4.61: Schematic of aggregate skeletons for asphalt mix types



Source: Austroads (2013).

Table 4.12: Wearing course texture depths

Wearing course surface	Texture depth (mm)
Spray seals, 10 mm or larger	> 1.5
Grooved concrete	1.2
Exposed aggregate concrete	> 0.9
Open graded asphalt	> 0.9
Stone mastic asphalt	> 0.7
Spray seals, 7 mm	0.6–1.0
Slurry surfacing	0.4–0.8
Dense graded asphalt 10 mm or larger	0.4–0.8
Tyned concrete	0.4–0.6
Hessian dragged concrete	0.3–0.5
Dense graded asphalt, 7 mm	0.3–0.5
Broomed concrete	0.2–0.4
Fine gap graded asphalt	0.2– 0.4

Source: Austroads (2013).

Surface hazards

Surface deficiencies and objects within the travel lane increase the likelihood of a motorcycle destabilising. A deficiency or object on the travel surface may redirect a motorcycle's riding path onto the shoulder or into the head-on zone or destabilise the motorcycle as a result of either direct contact or undertaking evasive action.

Surface deficiencies and hazards present the highest crash risk to a motorcycle on curves and in areas where the motorcycle will be braking such as and curve approaches, intersection approaches or during heavy braking and evasive manoeuvring.

A surface hazard can be a part of the road surface permanently or temporarily. An object is likely to be permanently placed on the road surface by design whereas a temporary object is likely to be as a result of wear and tear, maintenance and construction activities or debris dropped by vehicles or moved onto the road surface by wind or water. Any permeant object that is placed on the road surface should be done so with consideration to an expected motorcycle riding path.

Some examples of permanent and temporary surface hazards are as follows:

- permanent objects such as:
  - service covers, particularly when higher or lower than the surrounding road surface
  - raised pavement markers and rumble bars
  - kerbing (non-mountable) such as:
    - barrier kerb which will redirect a motorcycle and snag foot pegs (Figure 4.62)
    - particularly when isolated and not conspicuous (Figure 4.63)
    - kerbing protruding outside the shy line, particularly if not well delineated
    - barrier kerb on the inside of a turn at an intersection or roundabout
  - driveway ramps in the through lane (Figure 4.64)
  - joins between pavements and expansion joins
  - parallel grooving on concrete surfaces (this varies with groove width and the spacing between grooves)
  - speed humps, particularly the taper profile.

Figure 4.62: Barrier kerb for shoulder drainage and alternative traversable design

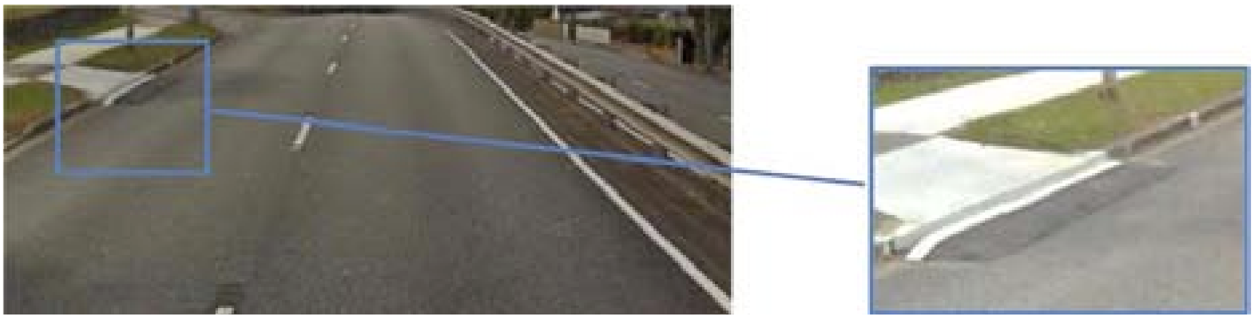
Barrier kerb on drainage treatment | *Traversable drainage treatment*

Source: Courtesy of ARRB Group and TMR.

Figure 4.63: Cold mix kerbing, not conspicuous

Source: Courtesy of ARRB Group and TMR.

Figure 4.64: Driveway kerbing in shoulder



Source: Courtesy of ARRB Group.

- temporary objects
  - deteriorated road such as:
    - rutting (particularly longitudinally), potholes, unravelling, shoving, corrugations, construction joins and cracking (Figure 4.65 and Figure 4.66)
    - edge drop including height differences on the shoulder between new and old asphalt surfaces

- foreign objects and debris such as:
  - large gravel from the shoulder or driveways
  - rocks from cuttings
  - objects from vehicles (timber, bricks, work boots, tools)
  - fauna (moving or stationary/'road kill')
- construction and maintenance activities such as:
  - asphalt milling, ledges and drops between sunken or raised road surfaces, cold mix backfilling, namely, trenching works (Figure 4.67)
  - patch repairs that result in a difference in height between the repair and road surface, particularly longitudinal lines
  - temporary signage, bollards traffic cones on the shoulder
  - excavated trenches on the shoulder.

Figure 4.65: Deteriorated pavement on curve (ravelling and stripping)

Source: Courtesy of ARRB Group and DPTI.

Figure 4.66: Longitudinal cracking and construction joint

Longitudinal crack on intersection approach | *Pavement repair construction joint on curve* | *Longitudinal cracking on concrete slabs*

Source: Courtesy of ARRB Group and Centre for Road Safety (CfRS).

Figure 4.67: Sunken pavement (after trenching) across left turn lane

Source: Courtesy of ARRB Group.

4.4.7 Overtaking Provisions

The need or desire to overtake is typically a result of vehicle (a) wanting to pass vehicle (b) as vehicle (b) is unable to maintain the typical operating speed of the road. This may be a result of a low power-to-weight ratio of that vehicle which hinders the vehicle maintaining a high average speed on a road with multiple horizontal and vertical curves (rolling or mountainous terrain).

A motorcycle has a higher power-to-weight ratio than most passenger vehicles and, as a result, has a greater rate of acceleration and is often able to maintain higher average speeds over the length of a road. On a road where there is a notable difference in the average speed of passenger vehicles and motorcycles, the need for overtaking provisions is higher. A motorcyclist that is platooned behind a passenger vehicle is more likely to attempt to pass the slower vehicle as the motorcycle can accelerate quickly to pass the vehicle. This, however, increases the likelihood of a crash if a passing manoeuvre is undertaken at a location where:

- it is legal to pass (broken centreline), however, the overtaking sight distance is inadequate or deceleration and completing the overtaking manoeuvre is before a curve or crest
- it is legal to pass and overtaking sight distance is not met.

The likelihood of a crash involving a motorcycle overtaking another vehicle is influenced by the following:

- the frequency of safe and usable overtaking opportunities as determined by travel time of the slowest vehicle and not distance, as average speeds need to be considered. The degree of safety of overtaking provisions are in the following order:
  - passing lanes
  - broken centre lines with adequate sight distance
  - vehicle stopping bays (reliant on vehicles to comply, hard to regulate as a slow average speed is subjective)
- the length of the overtaking opportunity:
  - is the length long enough for a motorcyclist to pass the platoon of vehicles
  - is the length long enough to allow multiple motorcycles (riding in a group) to pass the platoon of vehicles

- travel purpose and the percentage of motorcycles:
  - more commuters from outer city areas are converting to motorcycles which places overtaking demand on lower order roads that may not have previously been required, particularly if higher traffic volumes on ‘low volume’, lower order roads are present in morning and afternoon peaks. These roads may not have passing lanes or legal overtaking opportunities with adequate overtaking sight distance, an example of this is in Figure 4.68.

Figure 4.68: Mountainous terrain route between Magill – Lobethal Road, South Australia

Notes:

- *The route between Lobethal and Magill (fringe of Adelaide) is a popular recreational route on weekends however it is also used for commuting to Adelaide during the week.*
- *The crash history indicates 45% of crashes occurred during weekdays and 55% on weekends.*

4.5 Intersection Crash Likelihood

Intersections inherently have a higher crash risk than midblock sections of road for all road user groups. This is due to the multiple conflict points through the intersection, the possibility of restricted sightlines being present and the inability of some road users to consistently select a suitable gap in traffic to undertake their required manoeuvre. As vehicles cross paths at an intersection, the likelihood of two vehicles colliding is higher than for a midblock section and the resulting relative speed may be high. If the layout of the intersection is unclear, confusion can result. Similarly, some road features used to clarify an intersection layout (signs, channelisation kerbing and pavement markings) can be a hazard to motorcycles in their own right.

The crash factors that affect crash likelihood at an intersection are in explained in detail in Table 4.13.

Table 4.13: Road infrastructure elements affecting the likelihood of a motorcycle crash at intersections

Elements	Example
Intersection type	Roundabouts – adverse crossfall on curves, surface water from blocked central island drains and irrigation systems. To negotiate the feature, a motorcycle is required to accelerate on the curve which can present a high risk of destabilisation if sufficient surface grip is not available, particularly where there is adverse crossfall. Entry and exit design speeds on roundabouts are designed for cars and other motor vehicles, not the speed of a motorcycle. Sight lines are designed assuming a motorist will slow and yield at the roundabout entry, a motorcycle can often approach at speed and continue through the roundabout at speed, similar to a vehicle on multilane roundabouts. T-junctions – have fewer conflict points than a cross-intersection however the turning manoeuvres are less complex. As a result vehicles often turn at speed whilst only glancing to check for motor vehicles, a motorcycle is less likely to be seen. Cross intersections – the issues for a motorcyclist are the same as for vehicle crashes. Centre medians – a centre median along a midblock section is often found to have debris in it and, may not be wide enough for a motorcycle to store or stop midway through a U-turn manoeuvre.
Visibility	Motorcycles are susceptible to not being seen at intersections both when turning from the through lane or side road with no right turn lane. The presence of motorcycle on the through road is less conspicuous when the intersection is located on or over a crest and on the inside of a curve.
Line of sight	Safe intersection sight distance (SISD) and Approach sight distance (ASD) allow a motorcyclist to reduce speed to scan for a vehicle on the side road (SISD) or yield (ASD). The stopping distance will vary on dependent on the road surface condition, the motorcycle's braking technology and the motorcyclist's experience. The design stopping distance may not be sufficient to avoid a conflict, if the line of sight does not provide the minimal distance as per design standards the risk of loss of control or a collision with another vehicle is increased.
Turning provisions	A motorcycle making a right turn from the through road or side road at an unsignalised or signalised filter right turn is left exposed to through traffic. Motorcycles may not be identified on a through road by a motorist making a right turn on a right filter or signalised right turn. Motorcyclists may not be seen when in the inside lane of a dual lane turn and cut off by a vehicle that crosses the continuity/turn line markings.
Horizontal geometry	Due to the braking and handling characteristics of a motorcycle an intersection conflict point located on a curve (through road, slip lane or roundabout) is more difficult for a motorcycle to undertake evasive action without becoming destabilised.
Advance signage	A lack of advance directional or warning signage or unclear or cluttered signage does not allow a motorcycle to identify an upcoming intersection. This may lead to heavy braking, lane changes or re-directive manoeuvres which all introduce crash risk.
Carriageway width	A wide lane and shoulder will provide more manoeuvring width for a motorcycle to avoid a collision.
Road surface texture, drainage, condition and hazards	The issues are the same as for the midblock however more critical in the event braking or a re-directive manoeuvre is being undertaken to avoid a collision.

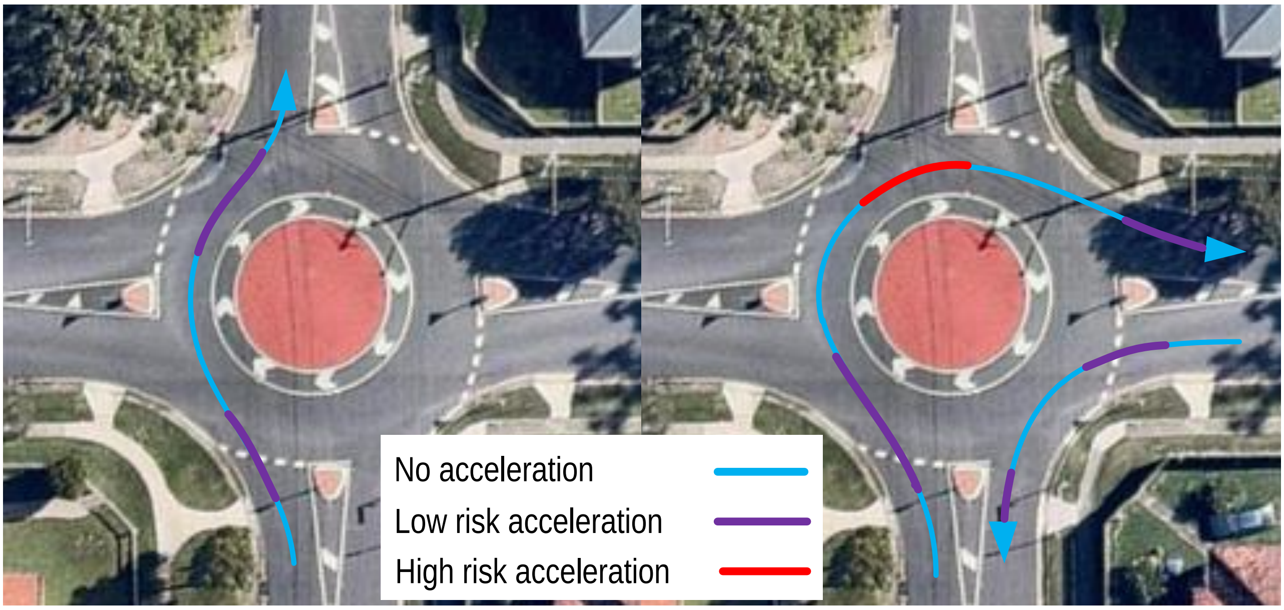
4.5.1 Intersection Type

Every intersection type has inherent risks due to its number of conflict points, intersection controls, observation angles, approach angles and resulting relative speeds, sight lines, drainage and interaction with other road users (pedestrians, cyclists, etc.). Some of these risks, however, can have a different effect for motorcycles than passenger vehicles. Additionally, a motorcycle is exposed to different risks and required to handle differently depending on the intersection type.

Roundabouts

A motorcycle is required to lean on the circulating carriageway whilst accelerating or braking. This places a higher demand for grip which can sometimes exceed the available grip in the case of acceleration of the rear tyre (Figure 4.69). A 'small' (tight) radius for the roundabout places a high demand on surface friction when the motorcycle is turning and accelerating whereas a large radius places demand on surface friction given that the motorcycle's speed will typically be greater. A hazard-free surface with good drainage and surface texture is recommended to reduce the likelihood of a motorcycle destabilising on a roundabout.

Figure 4.69: Typical acceleration zones on roundabouts



Notes:

- *These acceleration zones represent best riding practice and are the minimum number of times required to accelerate for each manoeuvre.*
- *Acceleration on other parts of the circulating carriageway will also result in a high risk acceleration which however, can be avoided with good riding technique.*

Source: Nearmap (2015), 'Seville Road and Glindermann Drive, Holland Park West, Queensland', map data, Nearmap, New South Wales, Australia

Some features of a roundabout that influence the likelihood of a motorcycle crash are:

- adverse crossfall on curves
- surface water from blocked central island drains and irrigation systems
- inadequate surface texture on the circulating carriageway
- the radius of the circulating carriageway

kerb profiles (preferably mountable kerb flush with the road surface) and delineation of kerbs

- entry and exit design speeds
  - designed for motor vehicles and not motorcycles (i.e. the geometry is not likely to force a reduction in the speed of a motorcycle)
  - sight lines are designed assuming the road user will slow and yield at the roundabout based on the entry speed geometry
- the angle of the intersecting leg and entry curve can reduce the observation angle to oncoming traffic
  - a motorcycle is less conspicuous than a passenger vehicle and is unlikely to be seen if the observation angle is reduced

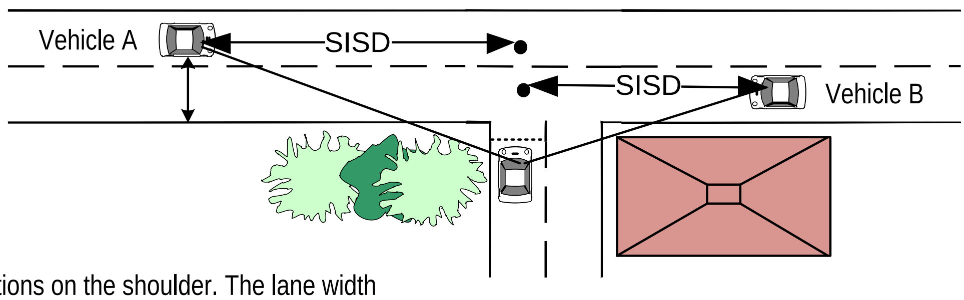
- identification of the roundabout from the approach including the centre island, kerbing on the approach and the radius of the circulating carriageway
- the roundabout layout and curve radius of the circulating carriageway can be unclear from the approach and this may result in a motorcyclist not selecting a speed that is appropriate for the curve radius of the circulating carriageway
- if the radius of a circulating carriageway is not uniform (a constant radius), a compound curve is, in effect, created. This will result in a change in the riding path, increasing the likelihood of the motorcycle destabilising (Section 4.4.1).

T-junctions

A T-junction is traditionally recognised as having fewer conflict points than a cross-intersection and is generally recognised to be a safer alternative. The simplistic nature of a T-junction, however, is thought to have an adverse effect on motorcycles – they are less likely to be seen. This is considered particularly prevalent with left-turn manoeuvres as a motorist only has to observe the right for oncoming vehicles. If the minor leg or left turn treatment has a poor approach angle, the observation angle may be reduced and the angle may encourage a high speed entry to the major (through) leg.

It is also considered possible that T-junctions may be less conspicuous from the approaches on the through leg, particularly if turning treatments or intersection channelisation (kerbing) are not present. This is more likely to be prevalent on the lane adjacent to the intersecting road, particularly if the sight lines are reduced due to geometry or objects on the shoulder. Early identification of the presence of an intersection reduces the need for a motorist to undertake heavy braking or evasive action to avoid a potential collision.

Figure 4.70: Identification of the intersection side road from each approach on the through road



If there are sight line restrictions on the shoulder. The lane width allows for a better line of sight to the intersection road for vehicle A.

Cross intersections

The issues for motorcyclists and other drivers are similar at cross intersections.

The most influential crash likelihood factor is a combination of high traffic volumes and motorcycles being less conspicuous. This results in motorcycles being more susceptible to being hit when turning through the intersection and crossing opposing traffic streams. This is most prevalent at intersections with high volumes of traffic as road users are pressured to make turns when less than ideal gaps are available. Such a scenario often results in motorcyclists and motorists making turns without thoroughly checking for other vehicles, a behaviour that increases the likelihood of a motorcycle not being seen and being struck. Often higher severity crashes result due to the impact angles, i.e. through – through, right – through and through – right crashes all have impact angles at or close to 90 degrees.

Centre medians

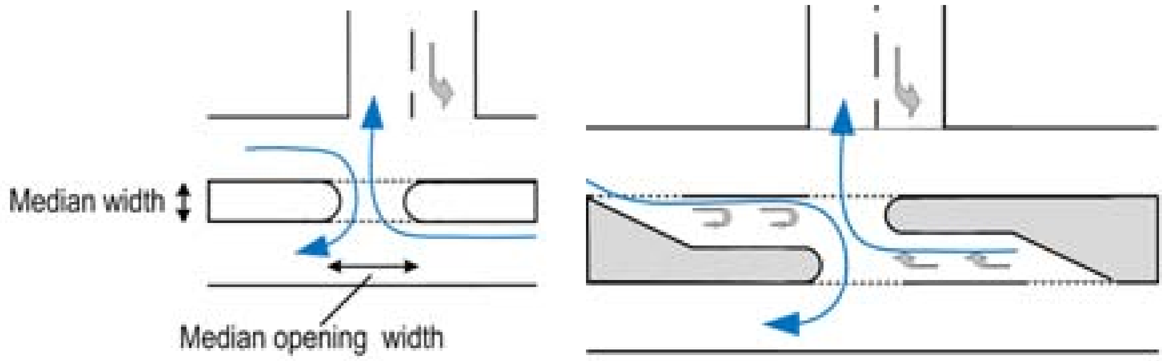
A centre median will require a motorcycle to decelerate to enter a narrow opening in order to stay within the median. The speed reduction required and likelihood of a motorcycle staying such that it is clear of through traffic is also dependent on the presence of any turn treatments at a median opening (Figure 4.71).

The median and opening width has an effect on:

- the speed required to enter the median opening in that:
  - a short median opening and narrow median will result in the motorcycle needing to reduce speed (almost to a stop) to enter the median before positioning the bike clear of traffic and avoid the kerb and any debris within the median
- the storage angle and the turning radius of a motorcycle in that:
  - a narrow median width will result in a motorcycle often being forced to stay at an angle within the median so as the front or rear of the motorcycle is clear of the through lanes
  - a motorcycle's storage angle affects the rider's observation angles and the stability of the motorcycle when accelerating from a stop, particularly when continuing a tight turning path (U-turn or turn into side road).

Due to their weight and high centre of gravity, motorcycles are prone to tip over during low speed manoeuvres with tight turning circles. This is an issue at medians as the turning manoeuvre is usually done from a stop/start or at low turning speeds. The risk of tipping is higher if debris is present as it may cause the motorcycle tyre or a motorcyclist's foot to lose traction on the road surface.

Figure 4.71: Centre median openings



Note: Motorcycle deceleration is required in the through lane. A motorcycle may be stored at an oblique angle to fit within the median width. A motorcycle may protrude into either of the through lanes.

Note: Vehicle deceleration in the U-turn or right turn lane. The median opening width is increased by the turn lane, motorcycles are protected in the turn lane, face oncoming traffic, are able to stop at a favourable location to complete the turn at a desirable radius.

Railway and tram crossings

A railway or tram crossing often presents a number of risks to motorcyclists (Figure 4.72) including the presence of the tracks (slight difference in levels and skid resistance), pavement markings and the adverse effect of the feature on road surface condition. Road surfaces around tracks and crossings are notoriously difficult to maintain and the presence of the tracks often results in undulations on the road surface even where the constituent materials are in good condition.

The following factors can have an adverse effect on motorcycle stability at railway and tram crossings:

- changes surface skid resistance and texture including changes from any surface repairs (Figure 4.72)
- pavement deterioration including loss of surface texture and roughness (Figure 4.73)
- loss of surface texture from tracks and pavement markings which are:
  - not perpendicular to the through road or on a turn
  - on or close to the hold line where braking and acceleration occur (Figure 4.74)
  - on the motorcycle turning path (Figure 4.75).

In urban areas, train and tram tracks will also often interact with intersections and, as a result, motorcycles are typically required to cross the tracks when moving through the intersection. The right turn manoeuvre is likely to involve the crossing of tracks. The presence of a hook turn reduces the likelihood of the motorcycle turning on the tracks, however, this may result in braking and acceleration on the tracks (Figure 4.74). A right turn without a hook turn is likely to result in the motorcycle turning, accelerating and braking on the tracks (Figure 4.75).

Figure 4.72: Railway crossing hazards

Note: Railway tracks perpendicular to through road, changing surfaces, slippery line marking, undulating surface, deteriorated surface texture.
Source: Google Maps (2016), 'Queensland', map data, Google, California, USA.

Figure 4.73: Railway crossing, road surface hazards

Source: Motorcycle Safety Advisory Council (2014).

Figure 4.74: Tram crossing, tracks on the braking and accelerating zone

Note: The motorcycle turns clear of the tracks but will brake on the tracks for some turns. Combined accelerating, braking and turning not present on low surface. Small radius turn required from hook turn hold line.
Source: Google Maps (2016), 'Melbourne, Victoria', map data, Google, California, USA.

Figure 4.75: Tram crossing, tracks on the turning path

Note: The motorcycle turns on the tracks, combining accelerating, braking and turning on tracks (low friction surface).
Source: Google Maps (2016), 'Melbourne, Victoria', map data, Google, California, USA.

Signalised intersections

Existing intersections tend to receive signals where high through and turning traffic volumes, or poor sight lines are present. Providing signals at an intersection will separate movements through the intersection, reducing the likelihood of crashes however the time separation of movements will create queues and hence, a speed differential between stopped vehicles and vehicles approaching the queue. This increases the likelihood of rear-end crashes, particularly with motorcycles given their inconspicuous nature. A motorcycle in a queue tends to blend into the vehicle in front of it, particularly if the vehicle is dark in colour. Motorcycles are also more difficult to detect at night.

If a queue has exceeded the designed storage length, sufficient stopping sight distance may not be available due to a sight restriction on the intersection approach. This leaves a motorcycle at the rear of the queue (or a few vehicles from it) in a vulnerable position.

Legalisation of lane filtering for motorcycles is emerging within Australia, with a number of road agencies having already legalised motorcycles to move through slow moving traffic streams to reach the front of queue at intersections. Whilst this reduces the likelihood of a motorcyclist being directly or inadvertently subject to a rear-end crash it also increases the likelihood of a same direction rear-end or side-swipe/angle crash. The likelihood of a same direction crash is dependent on the lane widths/available between cars and a motorcyclist's skill level to execute slow speed manoeuvring between objects (passenger vehicles). Currently motorcycle storage is not provided at the front of the queue, this results in a motorcycle and adjacent passenger vehicles accelerating concurrently. A motorcycle has the power-to-weight ratio to accelerate ahead of passenger vehicles, however a rapidly accelerating motorcycle does increase the likelihood of a motorcycle destabilising, particularly at intersections where skid resistance may be deteriorated by wear and tear and/or contaminants such as debris, fuel and oil.

4.5.2 Intersection Sight Distance and Visibility

Visibility of motorcycle

A motorcycle is not always conspicuous, partly because the envelope of a motorcycle from the front and rear is narrow and partly as a result of drivers not specifically looking for a motorcycle. Often motorcycles and the clothing of their motorcyclists is dark in colour which further contributes to the low visibility. Dull colours can also result in the bike blending into the background. The low visibility of a motorcycle often results in multiple vehicle crashes where the passenger vehicle driver 'Looked but failed to see' (LBFS) (Motorcycle Council of NSW 2010). The likelihood of a LBFS-related multivehicle crash can be influenced by the sight lines and sight distances available at an intersection.

Intersection sight distances

Providing good sight lines at an intersection prevents incidents, hence the specification of (Figure 4.76) and approach sight distance (Figure 4.77). If a sight line at an intersection is restricted (Figure 4.78 to Figure 4.81) then the sight distance will be reduced resulting in a reduction in the available stopping distance before a potential collision.

When on the through road, safe intersection sight distance (SISD) allows a motorcyclist to:

- identify the presence of an intersection, particularly intersecting roads at rural T-junctions (Figure 4.70)
- identify a vehicle approaching from the intersecting road before it reaches the hold-line or preferably before it enters the intersection (Figure 4.79)
- view a driver to determine if the driver has seen the motorcycle which is achieved by firstly identifying in which direction the driver is looking and then trying to establish eye contact with the driver.

When on the intersecting road, approach sight distance (ASD) allows a motorcyclist to:

- identify the presence of an intersection.

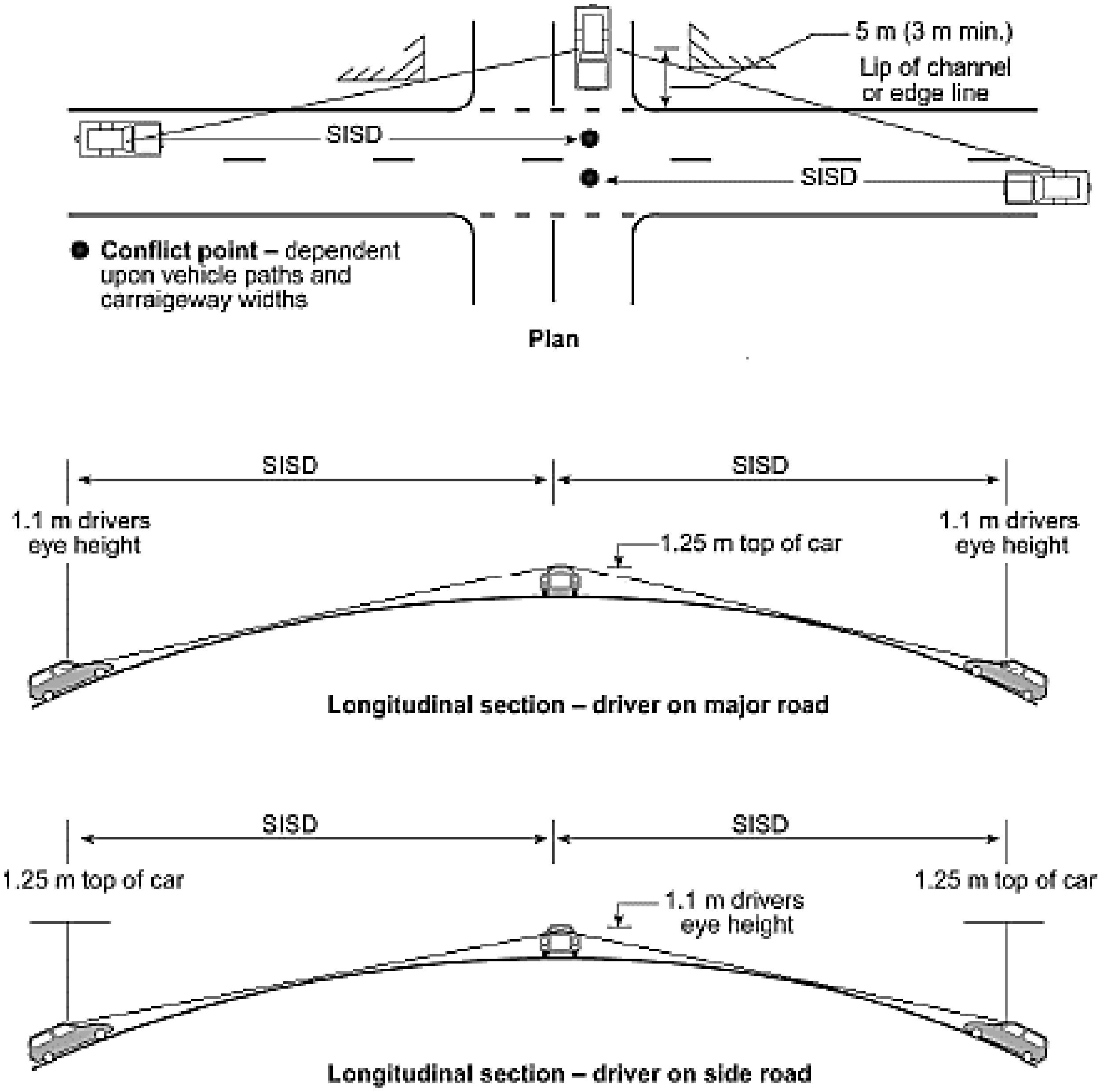
When on the intersecting road, SISD allows a motorcyclist to:

- identify vehicles on the through road
- identify suitable gaps to move through the intersection
- estimate the speed of a vehicle on the through road.

Early detection of an intersection will allow a motorcyclist to adjust their speed and scan the approaches for any vehicles and potential conflicts. This allows a motorcyclist to brake at a suitable rate reducing the likelihood of losing control from over-braking, needing to take evasive action or entering the intersection due to insufficient stopping distance before the intersection.

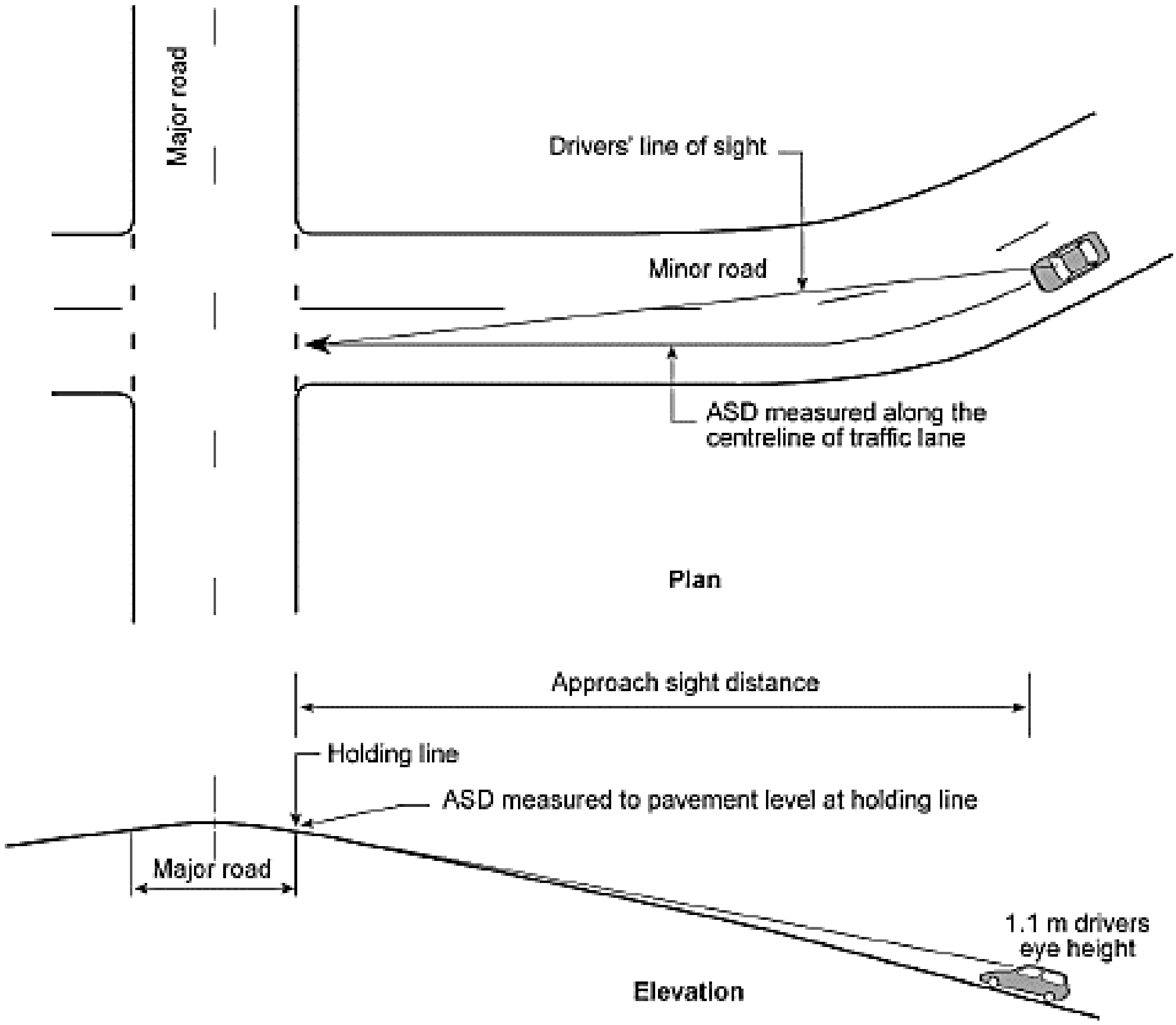
Consideration should also be given to the likelihood of a motorcycle stopping within the SISD and ASD. Motorcycle stopping distance can vary depending on the surface texture (or perceived surface texture), surface condition, weather, the motorcyclist's experience and/or the motorcycle's technology (Section 4.1). Shorter SISD or ASD distances calculated using minimum values such as quick reaction times, high co-efficient of deceleration rates and conservative operating speeds are unlikely to cater for a motorcycle to stop or avoid a collision without undertaking high risk evasive manoeuvres (Figure 4.82).

Figure 4.76: Safe intersection sight distance



Source: Austroads (2010).

Figure 4.77: Approach sight distance



Source: Austroads (2010).

Figure 4.78: Urban – restricted safe intersection sight distance

Figure 4.79: Rural – restricted safe intersection sight distance and visibility to side road from approach

Source: Courtesy of ARRB Group.

Figure 4.80: Rural – restricted safe intersection sight distance

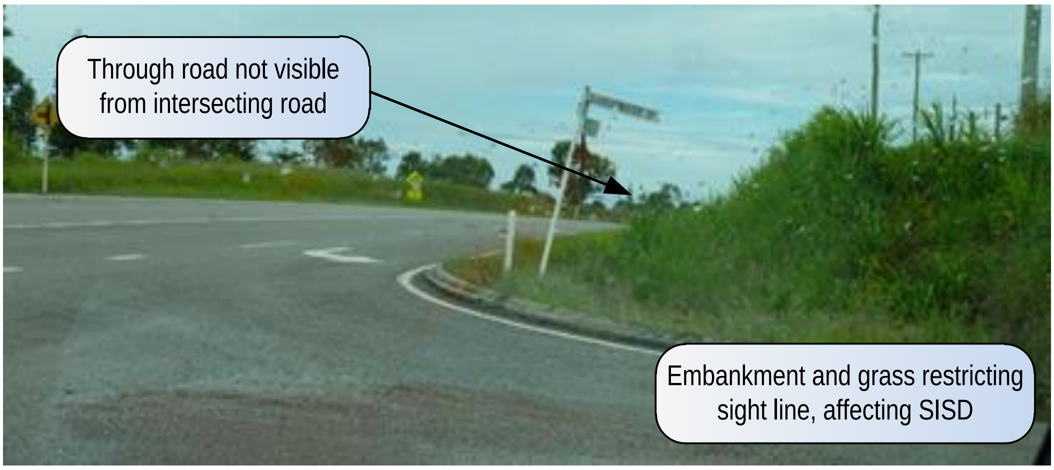
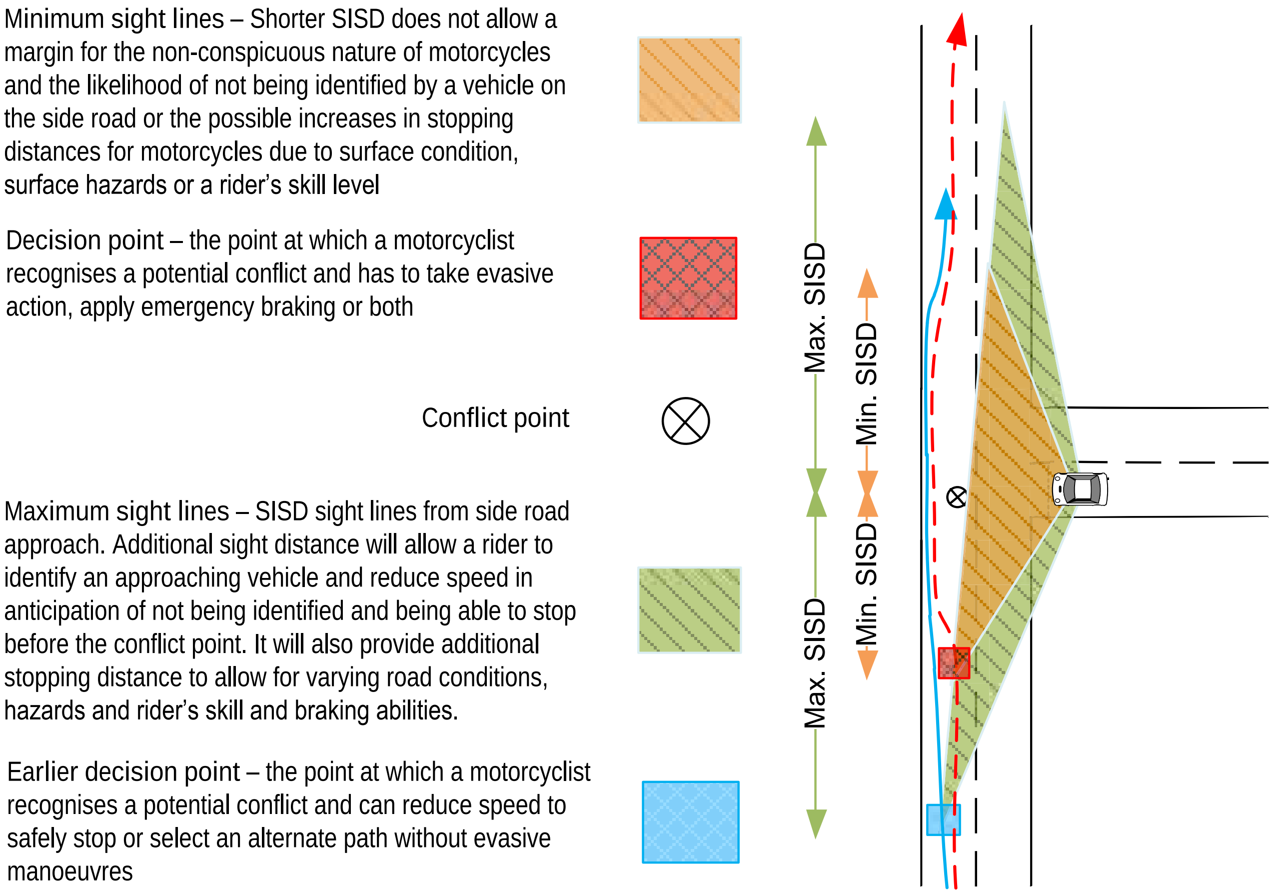


Figure 4.81: Roundabout with and without restricted sight lines due to landscaping

Restricted sightlines
Source: Courtesy of ARRB Group and TMR.

Unrestricted sightlines
Source: Google Maps (2016), 'Queensland', map data, Google, California, USA.

Figure 4.82: Effects of using minimum and maximum SISD

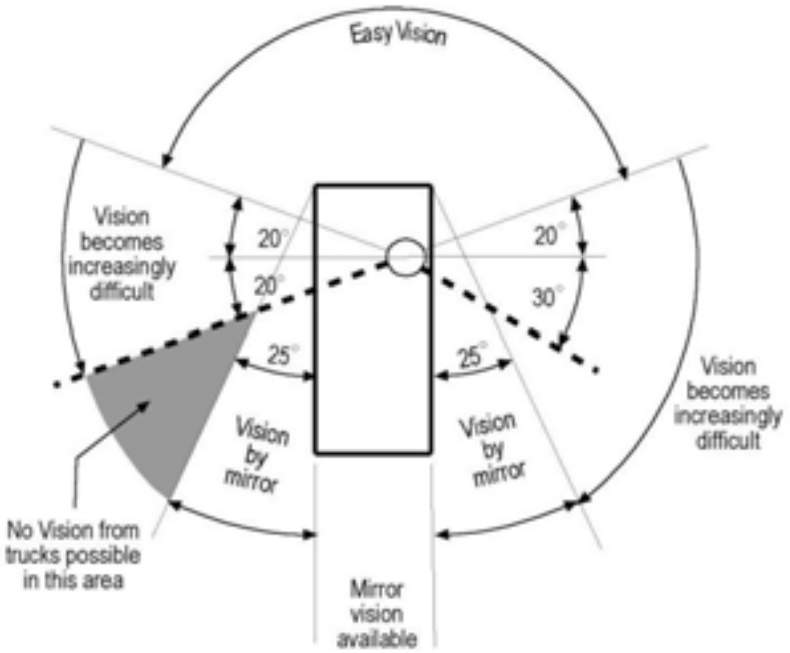


Observation angles

The design of passenger vehicles means that drivers have different observation angles to motorcyclists. The clarity of vision from the vehicle (observation angle) varies from 'easy vision' to more difficult angles and, finally, to a reliance on the side and rear view mirrors (Figure 4.83). Due to the inconspicuous nature of a motorcycle, a vehicle should be able to view an oncoming motorcycle within the 'easy vision' observation angle.

Intersection sight lines can be obscured by the angle at which the minor leg of the intersection meets the major (through) leg. This is particularly prevalent when left turn facilities are provided. This results in a road user on the intersecting road not being perpendicular to the through road which, when combined with observation angles (Figure 4.84), results in poor visibility to vehicles on the through road. This influences the likelihood of a road user on the intersecting road identifying a motorcycle on the through road.

Figure 4.83: Visibility angles and sight restrictions due to vehicle design



Source: Austroads (2010).

Figure 4.84: Poor visibility angles to through road

Note: The observation angle is obscured due to the intersecting angle of the left turn treatment. The observation angle is further restricted due to the horizontal curve on the approach of the through road.
Source: Nearmap (2015), 'Northern Territory', map data, Nearmap, New South Wales, Australia.

4.5.3 Turning Provision

A motorcycle is not always conspicuous, motorcycles reducing speed, stopped or turning through the intersection are particularly difficult to detect. As a result any turning provision should ideally:

- protect a motorcycle from through traffic or traffic approaching from the rear
- separate opposing movements with signals.

A turning provision that will contribute to a motorcycle being more difficult for other road users to identify should not result in obscure observation angles for a motorcycle or passenger vehicle (Figure 4.85).

Turning from the major (through) road

A motorcycle turning right from the major (through) lane is required to decelerate and possibly stop in the through lane before turning. This results in the motorcycle being exposed to a rear-end collision by following vehicles. Motorcycles are also vulnerable when carrying out turning movements across the intersection, however, these crash types are typically related to driver/rider behaviour, i.e. gap selection and conformance with intersection control provisions.

A motorcycle turning left from the through lane is required to decelerate and possibly stop before turning. The left turn, even though not crossing opposing traffic, may be done at low speeds. The turning speed is dependent on the turn radius and condition of the road surface. A motorcycle decelerating in the through lane and turning at low speed from the through lane is exposed to a rear-end collision from following vehicles.

A channelised right turn lane (CHR), auxiliary left turn lane (AUL) or channelised left turn lane (CHL) on the through road will:

- provide an area to decelerate after diverging from through traffic
- separate and protect a motorcycle from through traffic whilst it is stopped or turning
- allow a motorcycle to select a suitable gap in traffic to complete the turn and not feel pressured to undertake a risky turn to remove itself from the through lane where it is exposed to a rear-end collision.

Some factors that affect the likelihood of a motorcycle crash when the motorcycle is turning from the through road are:

- sight line restrictions, to identify the presence of the intersection and to the intersecting side road (left turn) by motorcycles and passenger vehicles
- motorcycle stopping distances (Section 4.1) and the available sight distances
- the operating speed of the through lanes
- the volume and mix of heavy vehicles on the through road
- the existing left turn radius and resulting turning speed.

Turning from the side (intersecting) road

A motorcycle turning left or right from the side road is susceptible to the same challenges as a motorcycle turning from the through road. Due to queuing on the side road, the likelihood of rear-end collision may be higher. If the side road has only one lane, a motorcyclist may feel pressured to turn through the intersection using an unsuitable gap in traffic.

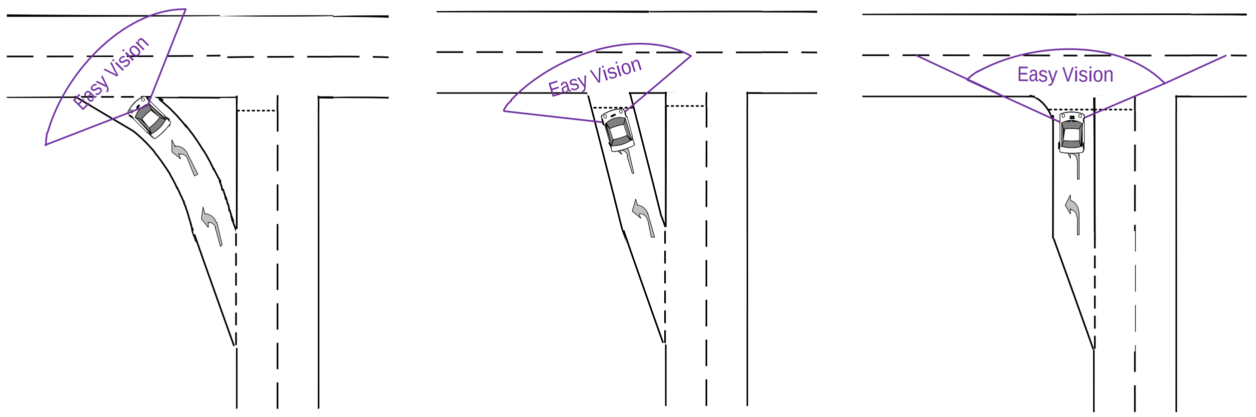
A left turn treatment on the side road may increase the likelihood of a crash if the angle of treatment is low and an acceleration lane is not provided (Figure 4.85). A low angle left turn treatment results in poor approach angles and observation angles (Figure 4.83) to traffic on the major road. This may result in hesitation at the hold-line and a driver alternating between checking for oncoming traffic and traffic at the give way line.

Also, a low angle left turn treatment may result in poor observation angles for a passenger vehicle at the hold-line. This influences the likelihood of side-swipe or angle collision with a motorcycle on the through road.

A right turn lane (preferably CHR) or high angle left turn treatment (CHL) or additional lane to turn left from (AUL) on the side road will:

- separate and protect a motorcycle from traffic whilst it is decelerating or stopped
- allow a motorcycle to select a suitable gap in traffic to complete the turn and not feel pressured to undertake a risky turn to reduce the risk of being hit from behind
- improve observation angles and sight distances (Figure 4.85).

Figure 4.85: Visibility angles resulting from left turn treatments



Note: Low angle left turn treatment with no auxiliary lane provided to enter the through road has very limit sight distance to oncoming motor vehicles/motorcycles.

Note: High angle left turn treatment has more sight distance within the easy vision range then a low angle treatment however it is dependent on the side road angle.

Note: Additional lane for left turn has the greatest sight distance within the easy vision range.

Signalised right turns

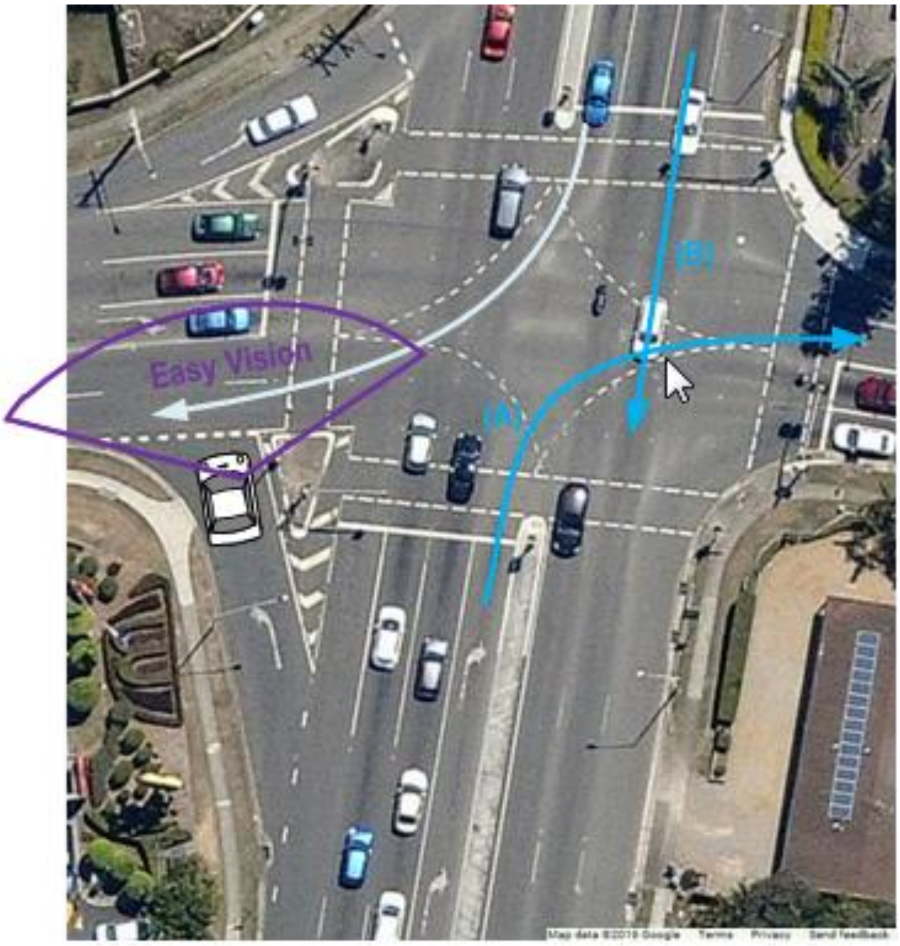
A filtered right turn lane is unlikely to reduce the likelihood of the following crashes occurring as a result of a motorcycle not being seen:

- a passenger vehicle in the through lane (Figure 4.86 – movement B) conflicting with a motorcycle turning right from the through lane (movement A)
- a motorcycle in the through lane (Figure 4.86 – movement B) conflicting with a passenger vehicle turning right from the through lane (movement A).

An intersection with a right turn lane and filtered right turns may be misleading:

- to a road user (motorcycle or passenger vehicle) in the right turn lane, particularly if right turn lanes at other intersections on the road/route have dedicated right turn phases
- to a road user approaching from the through road as there may not be an expectation that a vehicle may turn right in front of them. The sight line to the opposing right turn lane (where the vehicle will turn from) may be restricted by vehicles in the right turn lane of the through road.

Figure 4.86: Signalised right turn treatment and high angle left turn treatment



Source: Google Maps (2016), 'Carina Heights, Queensland', map data, Google, California, USA.

4.5.4 Intersection Location

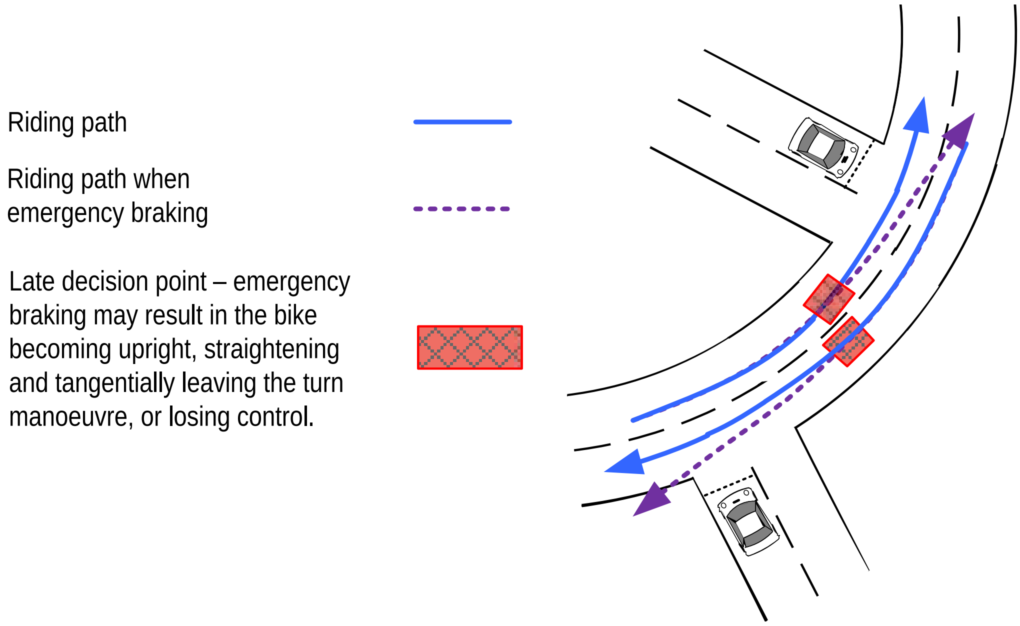
The location of an intersection may influence its sight lines, stopping distances and motorcycle stability when braking.

An intersection on a horizontal or vertical curve is more likely to be designed using minimum sight distances. This will result in an increased crash likelihood for motorcyclists due to reduced stopping distances and instability under heavy or emergency braking (Section 4.1). Further sight line restrictions such as advertising signage, roadside furniture or vegetation at an intersection may result in a passenger vehicle or motorcycle having inadequate distance to stop before a conflict point.

A motorcycle applying emergency braking or undertaking evasive action to avoid a collision or road surface hazard at an intersection on a curve is likely to:

- enter the opposing lane or shoulder as a result of emergency braking and the motorcycle straightening at a tangent (refer Section 4.1 and Figure 4.87) and:
  - if channelised, the motorcycle may destabilise by striking the central median or kerbing on shoulder
- become destabilised and enter the opposing lane or shoulder as a result of evasive action and:
  - if channelised, the motorcycle may slide into the central median or kerbing on the shoulder
- not stop before the conflict point as the motorcycle stopping distance may exceed the provided stopping distance for passenger vehicles.

Figure 4.87: Emergency braking or evasive action at an intersection on a curve



4.5.5 Road Surface

The road surface texture (by design and by condition after wear and tear), surface drainage and surface hazards influence the likelihood of a crash at an intersection similar to a midblock section of road (Section 4.4.6). The road surface, however, tends to have a greater influence on the likelihood of a motorcycle crash as the motorcycle and passenger vehicle movements are concentrated at a single location, often through gaps in traffic and whilst turning.

A motorcycle is more dependent on the road surface at an intersection (Figure 4.88) to allow for safe deceleration on the approach (Figure 4.89) and acceleration whilst turning through the intersection or turn treatment. This is particularly important for intersections with adverse crossfall and on circulating carriageways (with and without adverse crossfall) at roundabouts.

Due to the concentration of vehicle movements at an intersection, a motorcycle is more likely to use emergency braking or evasive manoeuvres to avoid a collision with another vehicle. The condition of the road surface will, therefore, affect stopping distances and the stability of the motorcycle.

Surface friction

A consistently appropriate level of surface friction ('grip') is required for a motorcyclist to remain stable during accelerating, braking, turning, cornering and whilst redirecting a riding path or taking evasive action. It is important to note that this is true in both dry and wet conditions, although the availability of 'grip' becomes highly significant in wet conditions. Often an urban intersection has an asphalt surface for structural purposes, however, such surfaces often provide/present limited surface texture depth resulting in the potential for surface friction 'grip' to be reduced in wet weather and when foreign material is on/in the wearing course.

Poor surface friction will affect the stability of the motorcycle when it is turning. A motorcycle on a roundabout will be most reliant on surface friction as the turn is continual on the circulating carriageway (Figure 4.69). Adverse crossfall on a circulating carriageway results in a higher reliance on surface friction to maintain 'grip' and motorcycle stability (Figure 4.90). Pavement arrows on a turning path or circulating carriageway (particularly with adverse crossfall) increase the likelihood of loss of 'grip' whilst the motorcycle is leaning through a curve/turn.

Asphalt often has low macrotexture depth (Figure 4.46). The macrotexture depth can be reduced due to a build-up of debris (oil, fuel, dirt) resulting in a loss of friction performance, particularly when the road surface is wet.

Details of factors that reduce or change surface friction and the resulting effects on the motorcycle are detailed in Section 4.4.6.

Surface drainage

Providing adequate/effective surface drainage at an intersection can be challenging, particularly on roundabouts and large urban intersections. Consideration should be given to the likelihood of effectively draining water from the intersection and how this will be achieved on wearing courses where the macrotexture (surface texture depth) tends to be low by design (Table 4.12).

The causes of poor surface drainage, its influence on the risk of aquaplaning and the resulting effects on motorcycles are detailed in Section 4.4.6.

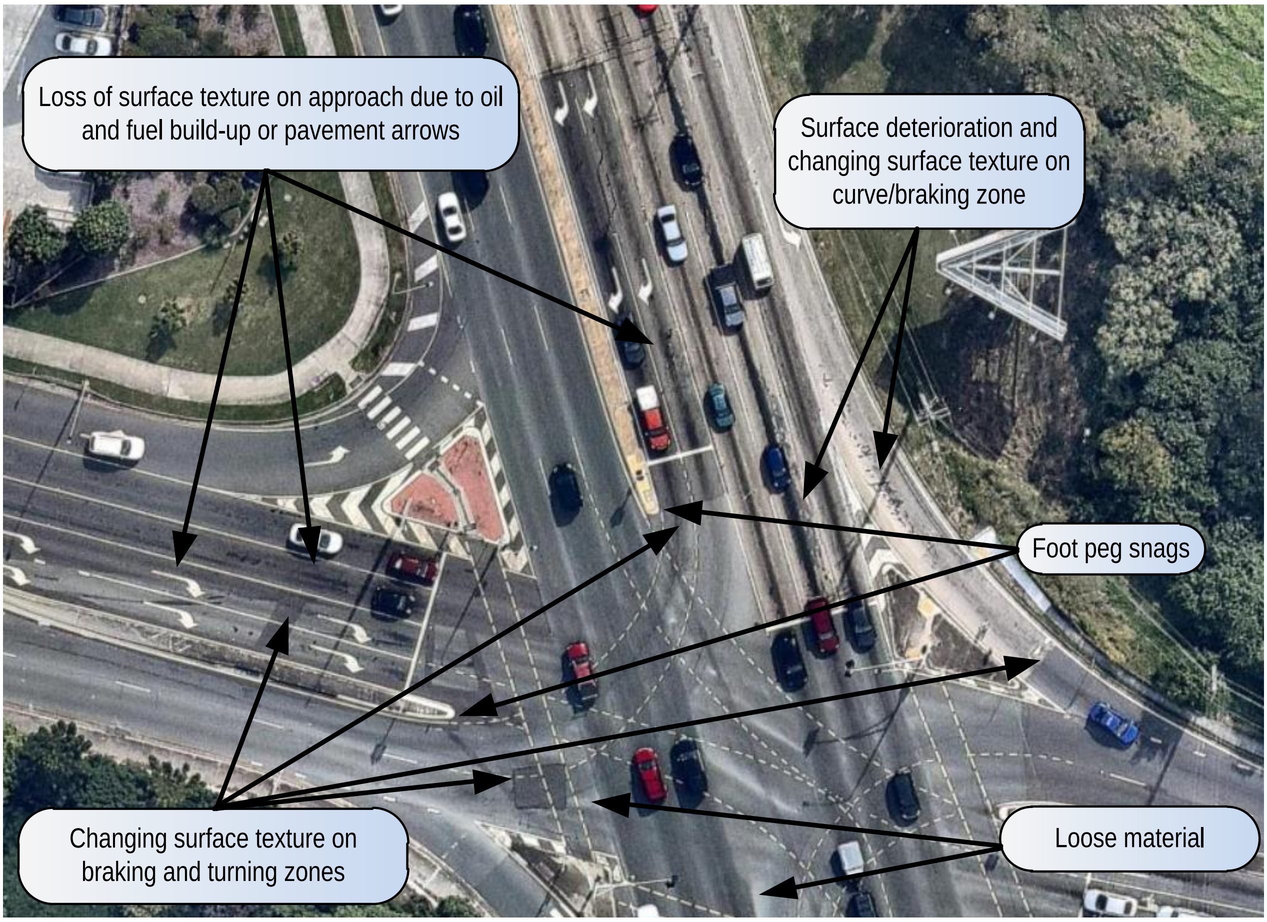
Surface hazards

Striking a surface hazard or attempting an evasive action whilst the motorcycle is already engaged in a steering, accelerating or braking manoeuvre increases the risk of the motorcycle destabilising.

The causes of surface hazards and their resulting effects on the motorcycle are detailed in Section 4.4.6.

It should be noted that a mountable kerb is likely to provide some redirection of the motorcycle however may provide opportunity for recovery. A semi-mountable kerb is likely to redirect the riding path of a motorcycle and a barrier kerb is likely to abruptly alter the direction of the motorcycle resulting in loss of control. A barrier kerb on the inside of a turn/curve at an intersection or on the circulating carriageway of a roundabout may snag a motorcyclist’s foot or foot peg, particularly if the kerb face is high (Figure 4.91).

Figure 4.88: Urban intersection – typical road surface issues



Source: Nearmap (2015), ‘Queensland’, map data, Nearmap, New South Wales, Australia.

Figure 4.89: Poor road surface on intersection approach – motorcycle braking and accelerating

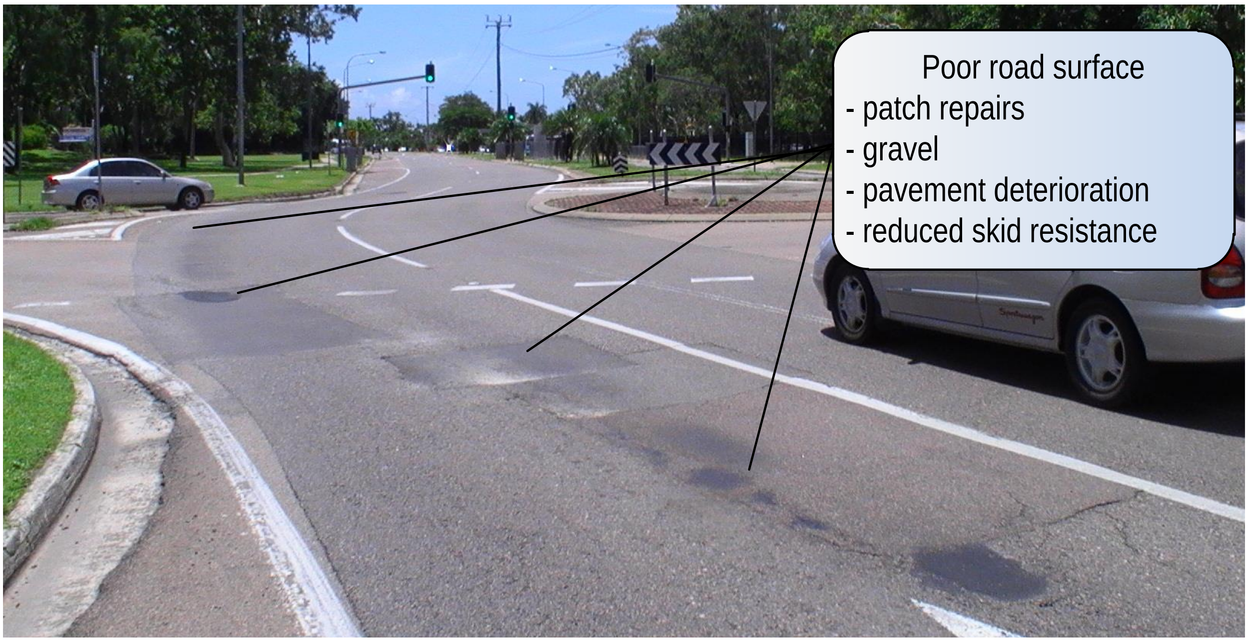


Figure 4.90: Poor road surface on roundabout circulating carriageway – motorcycle lean zone

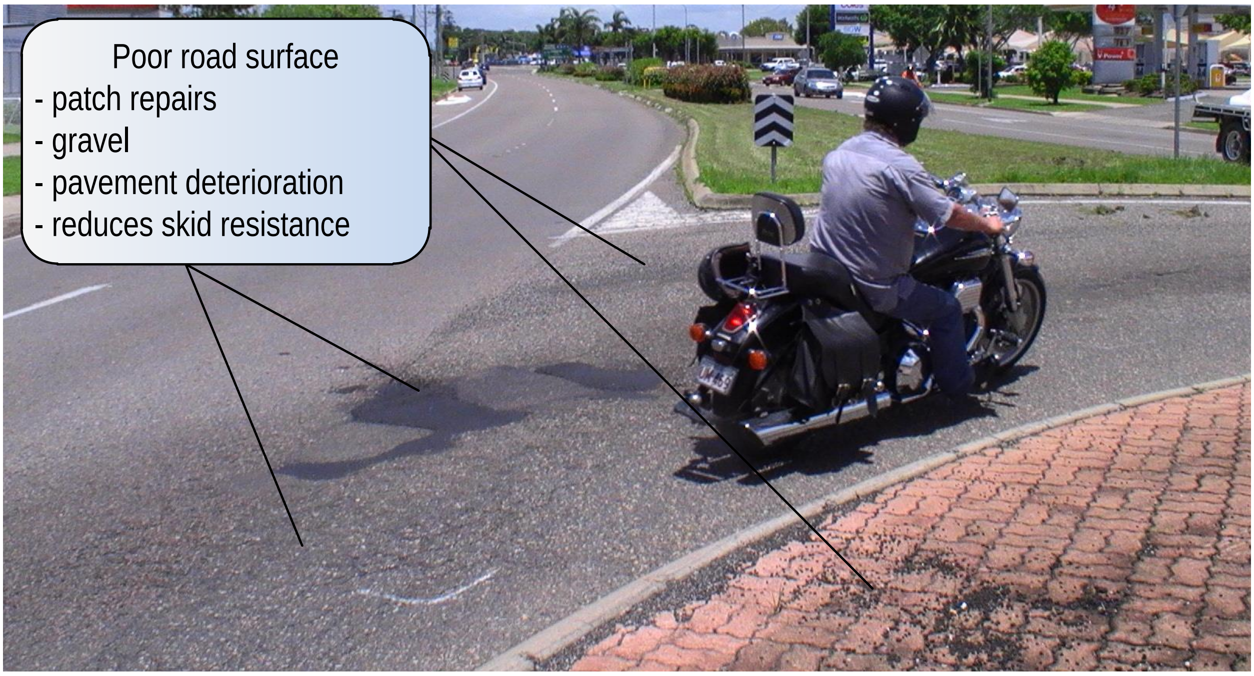


Figure 4.91: Barrier kerb on inside of motorcycle lean zone

Source: Courtesy of ARRB Group.

4.5.6 Carriageway Width

Manoeuvring width

As a motorcycle is not always conspicuous at an intersection, if the motorcyclist is decelerating in the through lane or has stopped to turn (from the through road or intersection road) then there is a risk of another road user crossing its path or hitting it from behind. In the event that a motorcycle is required to apply emergency braking to avoid a collision, the stopping distance may exceed the available distance to the conflict point and the likelihood of the motorcycle destabilising is increased (Section 4.1).

The likelihood of a motorcycle avoiding a collision can be reduced by increasing the carriageway width in the following ways:

- increasing the lane width:
  - can allow a motorcyclist to select a riding path which has a 'buffer' to a potential conflict point (Figure 4.92)
  - can provide a buffer between a motorcycle turning right from the through lane and a passing passenger vehicle (if a right turn provision is not provided), particularly on roads with heavy vehicles and multiple vehicle combinations with swinging rear trailers
  - can allow a motorcyclist to avoid a collision with a passenger vehicle that enters from the side road without striking median kerbing (if present), entering the head-on zone or crossing the centreline into the opposing lane (Vehicle (A), Figure 4.93)
- increasing the shoulder width:
  - can allow a motorcyclist to avoid a collision with a passenger vehicle that enters from the side road without the motorcycle leaving the formation (Vehicle (B), Figure 4.93). A motorcycle that leaves the formation during evasive action is likely to lose control.

Figure 4.92: Carriageway width and cautious riding paths

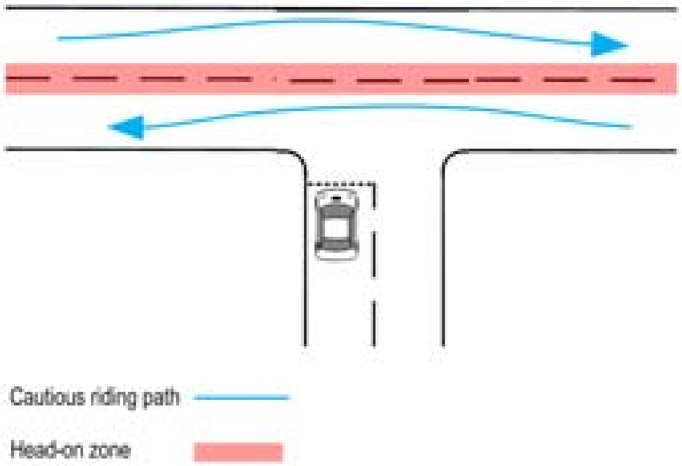
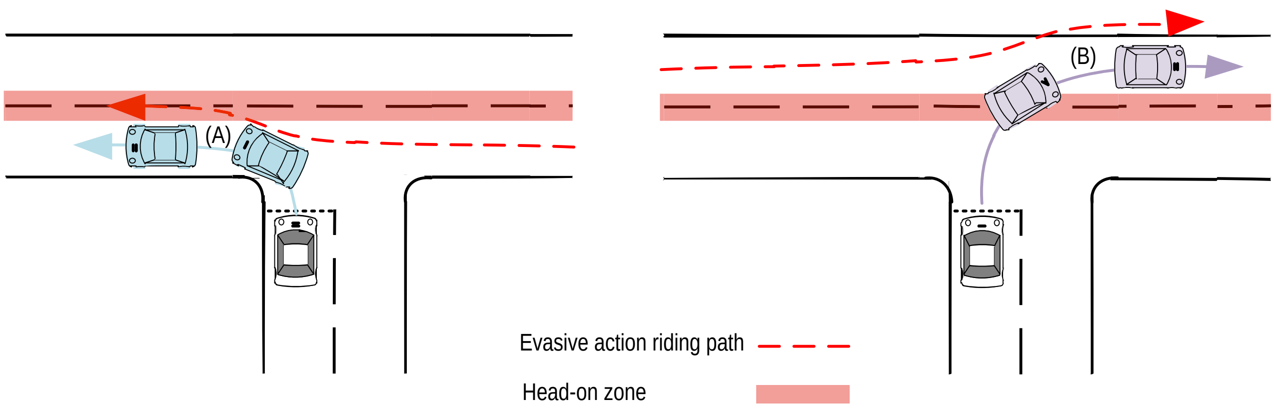


Figure 4.93: Carriageway width and evasive action to avoid a multiple vehicle collision



Lane filtering

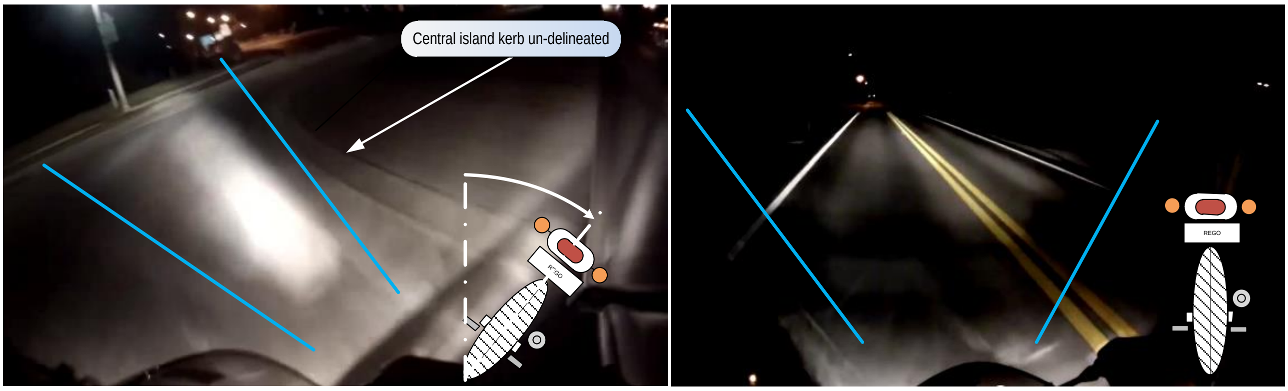
Whilst a motorcyclist is lane filtering the likelihood of a same direction crash is dependent on the lane widths/available between cars and a motorcyclist's skill level to execute slow speed manoeuvring between objects (passenger vehicles). A wider lane will allow clear passage and provide clearance between a motorcyclist and passenger vehicle.

4.5.7 Lighting, Delineation and Signage

The appropriate provision of lighting, delineation and signage at an intersection informs a motorcyclist of the presence of the intersection and its layout and any hazards present. This assists a motorcyclist to make safe and informed decisions about travel speed and riding path selection. Having adequate time to make decisions reduces the need for heavy braking and evasive manoeuvres which increase the likelihood of a crash. This is particularly important at intersections as a motorcycle entering such a feature in an uncontrolled manner (i.e. too fast or under heavy braking) is unlikely to be able to safely complete manoeuvres, avoid any surface hazards or avoid potential collisions with other road users.

Motorcycle headlights typically provide a dimmer and narrower light spread than a passenger vehicle. In addition, the available light provided by motorcycle headlights reduces as the motorcycle leans which can result in only a narrow section of the road being illuminated in front of the motorcycle when it turns (Figure 4.94), thus placing dependency on effective artificial lighting being provided at intersections, particularly roundabouts and on turning lanes.

Figure 4.94: Reduced spread of light when motorcycle is leaning on roundabout



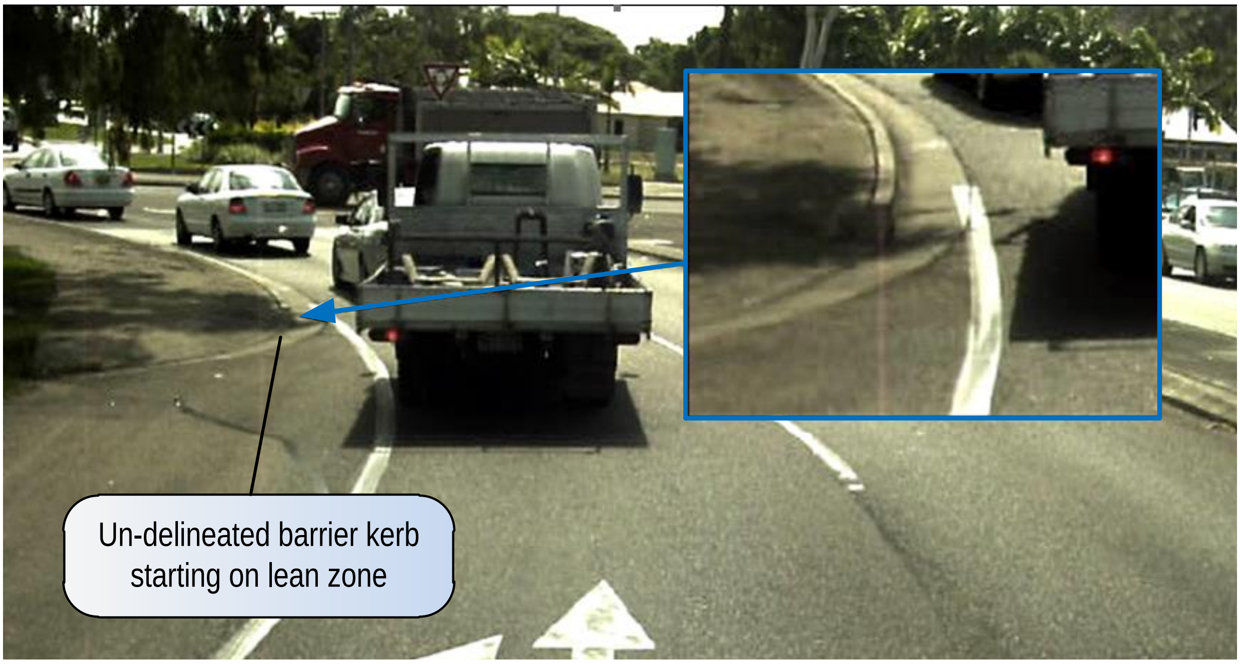
Motorcycle leaning to the right on a roundabout *Motorcycle upright on a straight*

Inappropriate lighting and delineation provisions at an intersection will influence crash likelihood if the following are not clearly identifiable:

- presence, geometry and control of the intersection, including:
  - the layout including turn provision lanes (Figure 4.95)
  - hold lines and intersection priority
  - turning paths through the intersection and on turn provisions
  - circulating carriageway radius at roundabouts
- hazards at an intersection (Section 4.4.6) including:
  - kerbing such as the centre median, splitter island or central island (Figure 4.96)
  - leading edge of raised medians, particularly if not well delineated
  - poor road surface including surface texture (or loss of surface texture), drainage or isolated hazards, all of which would require adequate lighting to be identified at night.

Figure 4.95: Poor lighting and delineation left turn lane and centre median crossing

Figure 4.96: Barrier kerb – non-delineated, a foot peg snag hazard within a lean zone



4.5.8 Intersection Signage

Signage in advance of an intersection provides both a warning and direction to a motorcyclist allowing them to prepare to change lanes, stop, turn or reduce speed (including to check for vehicles entering the intersection) and handle the motorcycle in a controlled manner. Heavy braking, weaving or sudden turning increases the likelihood of the motorcycle destabilising or being hit by another road user.

Signage should be clear and distinctive from colours or other signs in the background, conspicuous and located and spaced appropriately so that the sign is not too far in advance of the intersection to be effective but far enough away that a motorcycle can react in a controlled manner. It is suggested that, in some cases, providing a larger than recommended sign size can be highly effective, although this needs to be balanced by considering any signage as a point hazard in its own right. Larger signage can often require additional supports which have the potential to be struck. The benefit of the larger sign must outweigh the risk.

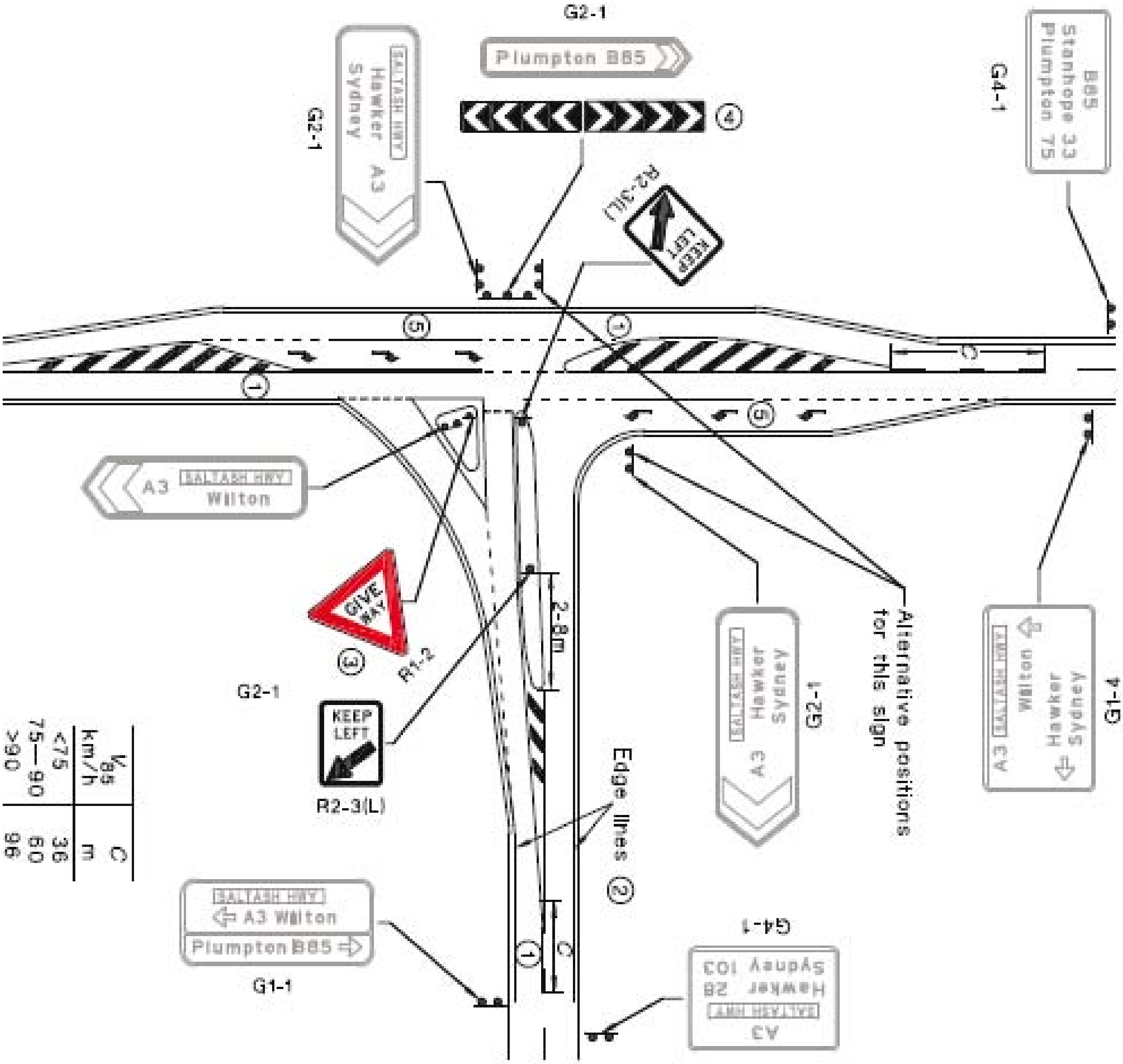
Intersection control (Give Way and STOP signs), direction signs and sight boards should clearly define the point at which the side road intersects with the through road.

An intersecting road that terminates at a T-junction should be clearly identified with a sight board (D4-4) which is usually accompanied by an intersection direction sign (G2-4). The use of an intersection signage layout which is not consistent with typical signage layouts (Figure 4.97) and does not reflect the intersection layout and intersection priority (Figure 4.98) increases the likelihood of a crash.

Clear intersection signage reduces the likelihood of a motorcycle or a passenger vehicle crash as it reduces the risk of:

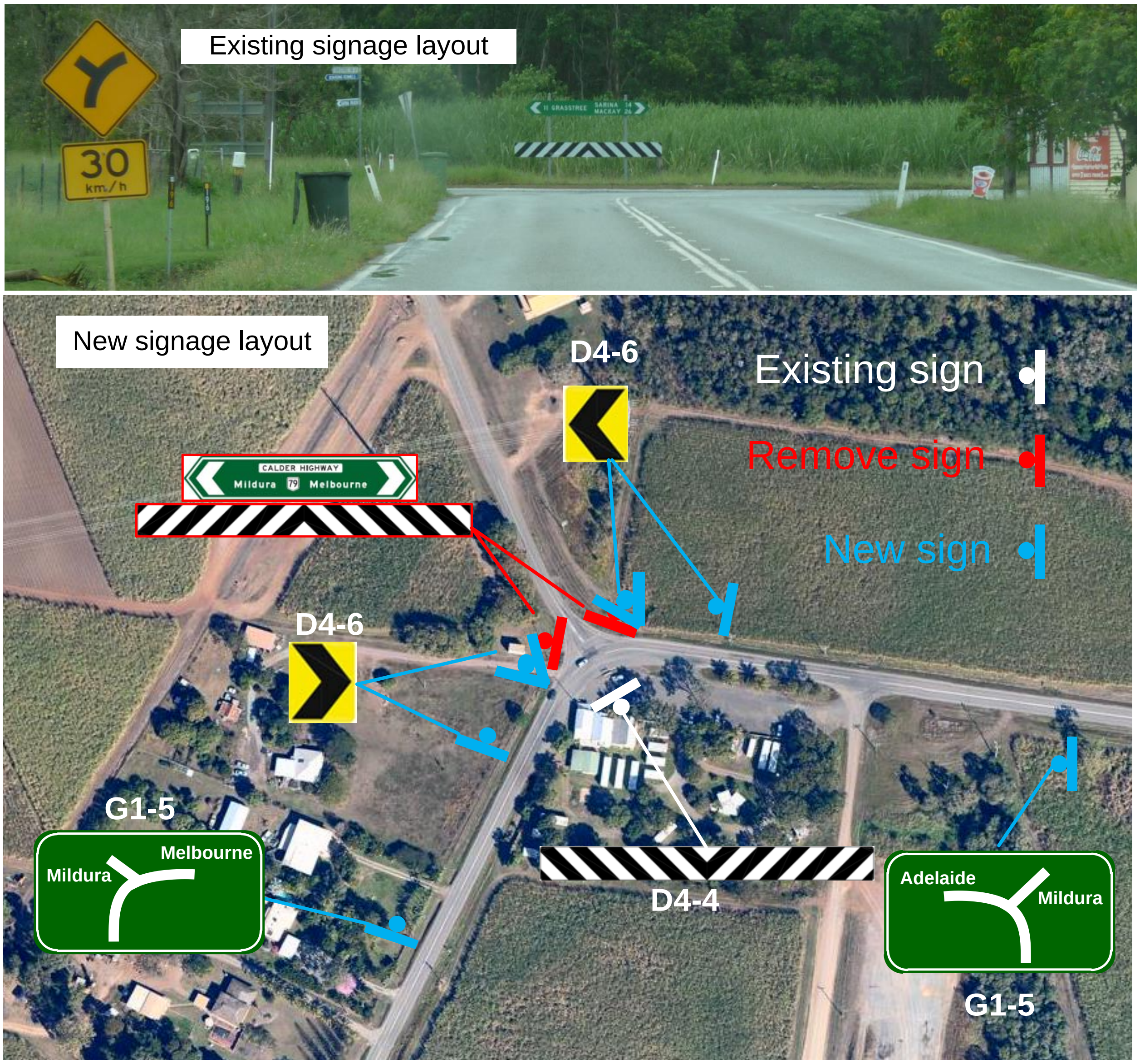
- riding/driving through the control (STOP or Give Way signs) provision if they had not identified the presence of the intersection
- applying heavy braking and sudden changes in riding/steering paths to change lanes or make a turn
- applying emergency braking or taking evasive action to avoid a collision as a result of not reducing speed to:
  - manoeuvre through a turn or around the circulating carriageway of a roundabout
  - deviate slightly through the intersection around raised kerbing for turn provisions
  - anticipate a vehicle entering from an intersection road.

Figure 4.97: T-junction with conventional signage plan



Source: AS 1742.2-2009.

Figure 4.98: Unclear T-junction layout, clarified with non-conventional signage plan



4.6 Crash Severity

The ultimate severity of a motorcycle crash is dependent on the impact forces experienced by the motorcyclist. A motorcyclist is more vulnerable to impact forces than other most other road users using motorised vehicles as they do not have an outer shell to protect them. An occupant of a vehicle is protected by the chassis structure and protective outer shell of a passenger vehicle. Further protection is provided by pre-tensioned seat belts and airbags. All of these combine to reduce impact forces to the occupant. A motorcyclist does not have the same protection that a vehicle occupant has and is likely to experience all of the impact force.

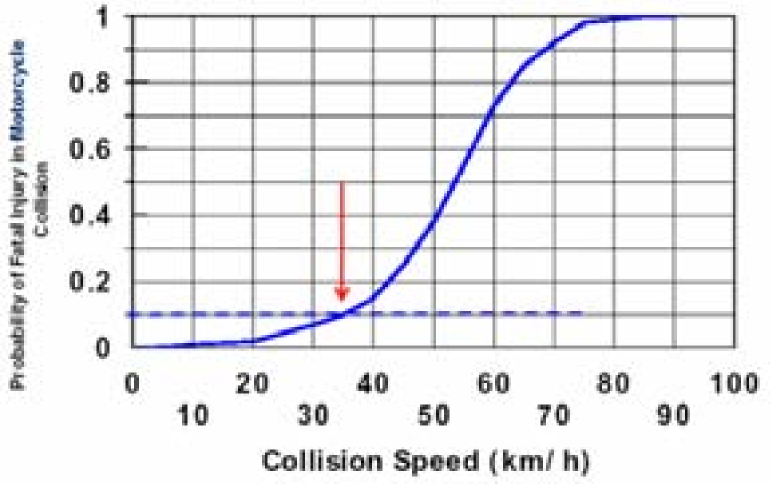
The impact force on a motorcyclist is influenced by:

- the collision speed
- surface area of the object or point of impact with another vehicle
- impact absorption properties of the object or vehicle
- angle of impact.

4.6.1 Collision Speed

The probability of survival of a motorcyclist who strikes a roadside object or another vehicle reduces rapidly as the collision speed (which includes relative speed in multiple vehicle crashes) increases above 35 km/h (Figure 4.99).

Figure 4.99: Probability of a fatal motorcycle crash by collision speed with roadside objects



Source: Rumar (1999).

Collision speed and posted speed limits

In a collision with a roadside object or another vehicle, the collision speed for the motorcycle is its speed when the impact occurs. This is not the posted speed limit or operating speed of the road.

The operating speed for motorcycles and passenger vehicles on a road will fluctuate e.g. reductions in speed are required to safely navigate curves (Figure 4.100) and roundabouts and to give way or check for vehicles at intersections.

As has been previously discussed, road infrastructure can influence the operating speed and hence, the collision speed in the event of any impacts (e.g. clear presence of an intersection or change in alignment).

The ultimate collision speed is largely dependent on the ability of a motorcycle to reduce its operating speed before the point of impact. The following allow an upright errant motorcyclist to reduce speed before the collision point:

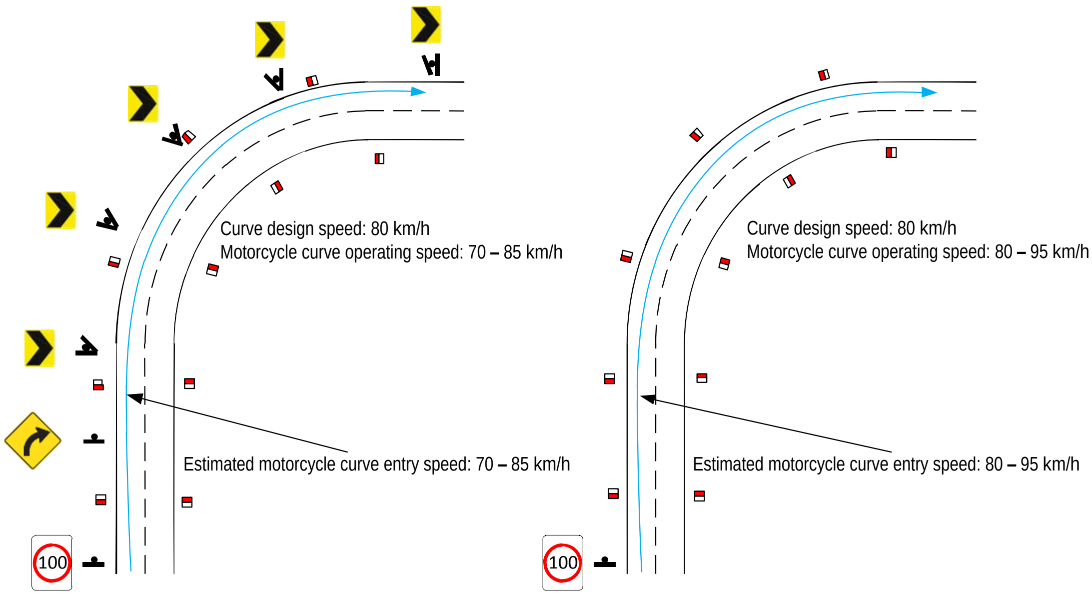
- the road surface (Section 4.4.6) in allowing the motorcycle to decelerate rapidly under brakes and remain upright, given that a sliding motorcycle is not likely to reduce speed as rapidly as an upright motorcycle under brakes
- the available lane or sealed shoulder width (Section 4.4.3) allowing for braking and recovery.

Single vehicle crash

The collision speed in a single vehicle crash is influenced by the speed of the motorcycle only. A low operating speed will result in a lower collision speed. The operating speed can be influenced by road infrastructure.

For horizontal or vertical curves and intersections, the operating speed should be managed through road infrastructure attributes such as sight lines, signage and delineation. These attributes allow a motorcyclist to identify the need to adjust to an appropriate operating speed. An example is shown in Figure 4.100.

Figure 4.100: Comparing operating speeds on curves with and without curve signage



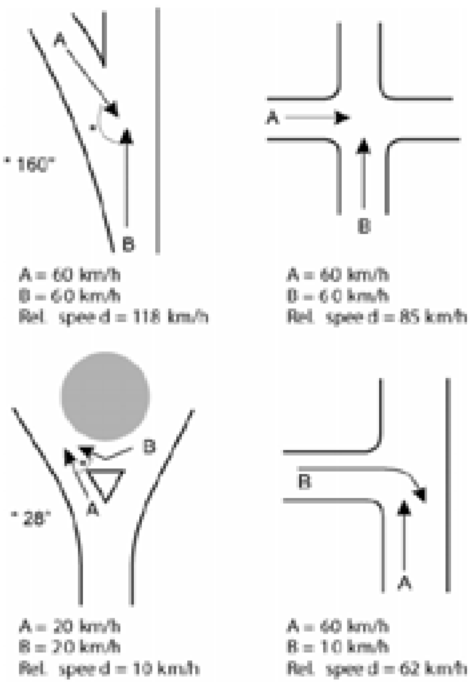
Notes:

- *The curve entry speed will vary depending on the sightlines through the curve, curve quality signage, surface condition, weather and a motorcyclist's skill level.*
- *The curve entry speed is likely to continue through the curve, thus is the operating speed for that curve.*

Multiple vehicle crash

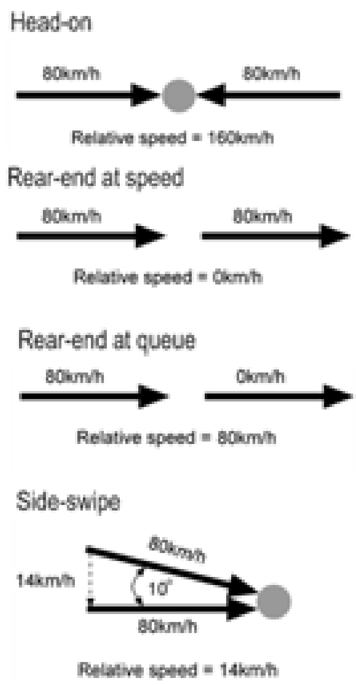
The collision speed in a multiple vehicle crash is due to the relative speed (Figure 4.101 and Figure 4.102). The relative speed is a result of the respective vehicle speeds and ultimate impact angle. This can be influenced by many factors including intersection type, layout, intersecting road angles, signage, delineation and intersection provision controls.

Figure 4.101: Potential relative speed at intersections



Source: Department of Main Roads (2006).

Figure 4.102: Potential relative speed on midblocks



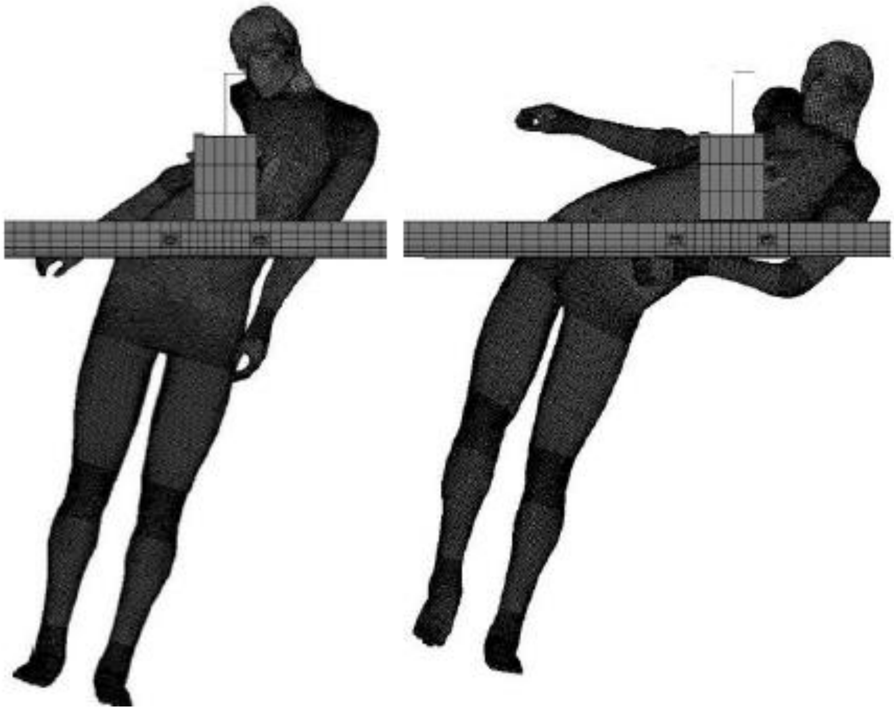
Note: due to the smaller mass of a motorcycle, when struck from the rear or side the motorcyclist may be pushed into a second object.

4.6.2 Surface Area

The impact forces on a motorcycle are concentrated to the point of impact. The subsequent distribution of force to the body of the motorcyclist is dependent on the surface area of the object. The following are examples of relative surface areas of the rider:

- a sign post has the smallest surface area resulting in the greatest concentration of force at the point of impact (Figure 4.103)
- a concrete barrier or W-beam safety barrier has a larger surface area and is likely to distribute the force across a larger point of impact
- barrier kerbing has a 90 degree edge on it which presents a small surface area
- the edges and corners of signs, safety barrier end terminals and posts are likely to cut into a motorcyclist and may cut through protective clothing.

Figure 4.103: Concentration of impact forces on motorcyclists



Source: Bambach and Grzebieta (2014).

4.6.3 Impact Absorption

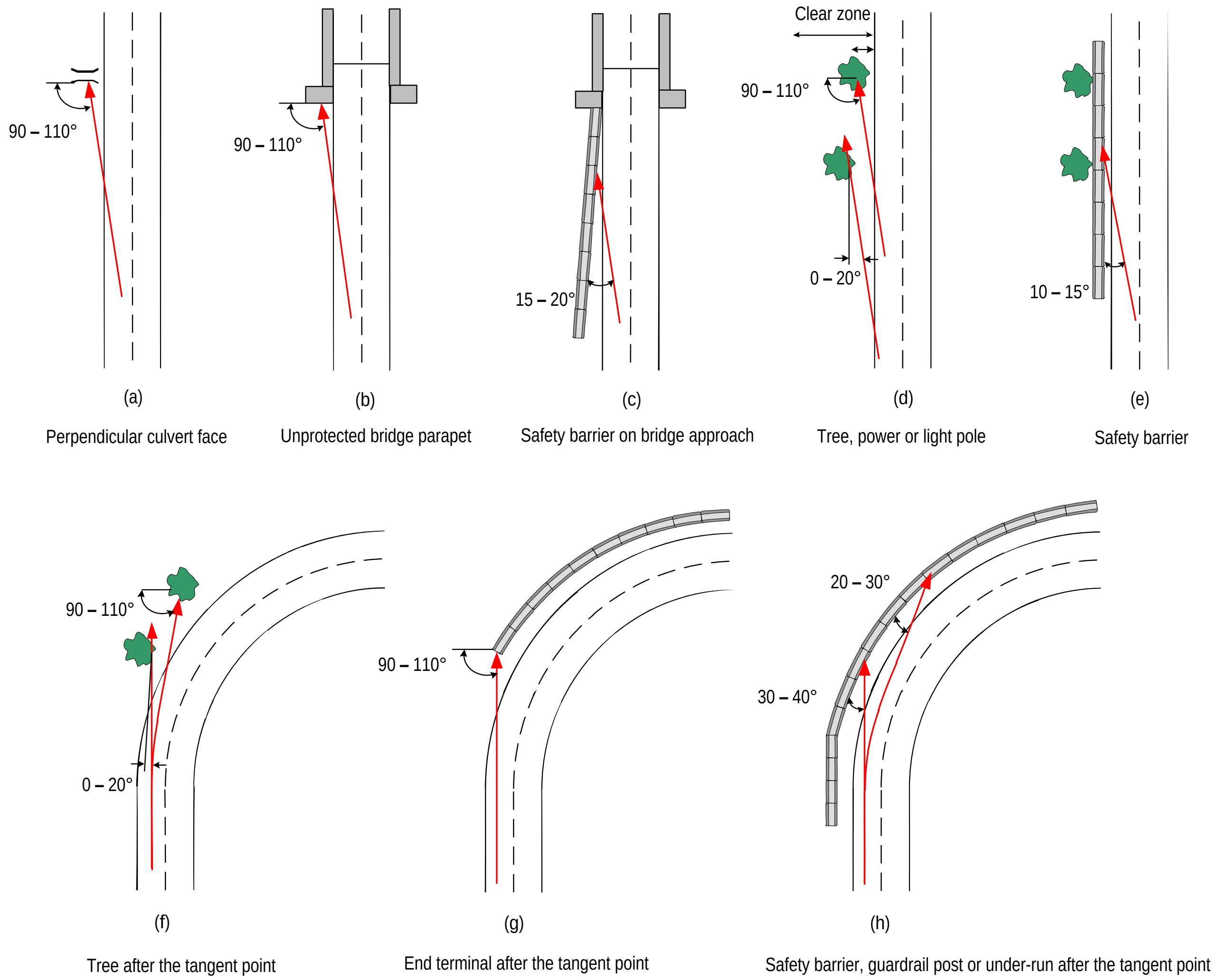
In motorcycle collisions, trauma to the motorcyclist's body is often violent and significant given the immediate rates of deceleration imposed on the human body. The impact absorption properties of an object that is struck by a motorcyclist (such as a roadside pole or another vehicle) does have some influence on the rate of deceleration to the motorcyclist's body. Vehicles tend to afford little impact absorption properties to motorcyclists whereas the same property provided by roadside objects can vary significantly based on their size/profile (e.g. area and shape), placement (e.g. spacing and location), their constituent materials and properties (e.g. concrete, steel, plastic) and their underlying design principles (e.g. whether it is frangible).

4.6.4 Impact Angle

In single vehicle crashes where a motorcycle leaves the carriageway, the size, location and orientation of the object which is struck will influence the angle of impact and ultimately whether a slow or rapid rate of deceleration occurs. Some examples of these are as follows:

- rapid rates of deceleration:
  - an object with a surface area that is perpendicular to the carriageway as shown in examples (a), (b), (d), (f) and (g) in Figure 4.104
- slower rate of deceleration:
  - an object with a surface area that is parallel or close to parallel to the carriageway as shown in examples (c), (e) and (h) in Figure 4.104
  - the angle of impact is likely to remain shallow when the object is long as shown in examples (c), (e) and (h)
- variable rate of deceleration:
  - an object that is short may have different angles of impact, this is shown in examples (d) and (f). This means that the angle of impact will vary depending on:
    - the angle of departure from the carriageway
    - the distance between the object and the through lane (effectively the road's clear zone).

Figure 4.104: Combination of object orientation, surface area and object length influencing angle of impact



4.6.5 Roadside Objects

Motorcyclists have a much greater risk of hitting roadside objects directly, particularly after being destabilised. Most roadside objects are non-frangible when struck by a motorcyclist. As a consequence, the kinetic energy must be dissipated through the body of the motorcycle or motorcyclists themselves rather than the object. If a motorcyclist collides with an object that has a small surface area, the crash force is concentrated on the point of impact.

A roadside object may be frangible by nature (small trees) or frangible by design (sign post) when struck by a passenger vehicle, however, in most cases these objects are not frangible for motorcyclists. Most roadside hazards can potentially cause serious or fatal injuries to a motorcyclist. All roadside objects are considered a hazard to an errant motorcyclist unless the object is specifically designed to be motorcycle friendly i.e. frangible or designed to absorb impact forces when struck by a motorcyclist.

Some examples of roadside objects that result in high motorcycle crash severity are provided in Table 4.14.

Table 4.14: Roadside objects that are a hazard to motorcyclists

Category	Roadside object
Roadside furniture	Sign posts (particularly multiple posts on the outside of curves for CAMs), sign faces, signal post, light posts, utility poles, large sign structures, guide posts, bus shelters, rubbish bins, bicycle rails, pedestrian and rock fall fencing etc.
Safety barriers	Steel guard rail with unprotected guard rail posts, steel guard rail with motorcycle under-run concrete barriers, end terminals, wire rope barrier posts and wire etc.
Utility services	Water pipes, water meters, power transistors, utility poles, wheelie bins, telecommunication exchanges etc.
Drainage	Stone pitched drain, drainage ditch, culvert headwall perpendicular to through road, culvert with steep drop off, headwall that is higher than the road surface, unprotected drainage pit opening, barrier kerb etc.
Natural environment	Trees (including frangible diameters for vehicles), boulders, vertical faces on cuttings (particularly if they have jagged edges or protruding rocks), cliffs etc.
Landscaping	Trees, boulders, statues/monuments, entry statement signage.

A roadside object may be a necessary part of the road environment (bus shelters, cuttings) and may in fact play an important role in reducing crash likelihood (sign posts for CAMs, light poles, safety barriers to divide opposing traffic). The following points should be considered when assessing the likelihood of a roadside hazard being struck and the level of severity associated with that roadside object:

- Is the object likely to be struck by an errant motorcyclist e.g. on the outside of a curve or centre island of a roundabout
- Will the surface area of the object and its orientation to the road result in high or low impact angles (pole on the outside of a curve compared to a safety barrier)
- Can the object be relocated:
  - power lines and water mains placed underground
  - light poles, utility poles and sign posts placed on the inside of curves or behind a motorcycle friendly safety barrier
- Can the object be replaced or substituted with a less severe alternative:
  - sign post and sign face replaced with a flexible post and sign face
  - crash cushions placed on safety barrier end terminals, sign posts or wire rope barrier support posts
  - guide posts replaced with a flexible alternative
  - culvert faces perpendicular to the through road replaced with traversable headwalls.

Roadside furniture

As mentioned previously, a roadside object may reduce the likelihood of a crash occurring e.g. curve quality signage (Figure 4.105), however, these pose a high severity risk if struck.

Fencing may be required to channelise pedestrian movements (Figure 4.107), prevent traffic movements from an arterial road to a service road or through the median of an arterial road (Figure 4.106) or to prevent fallen rocks entering the through road. The location and frangibility of the fencing should be considered.

Roadside furniture is most likely to be struck on the outside of a curve and at a higher collision speed. The placement of the roadside object should be considered (Figure 4.108) and motorcycle-friendly alternatives should be considered, particularly where a number of roadside objects are located in close proximity to each other and/or placed on the outside of a curve, the inside of an intersection turn or in the central island of a roundabout (Figure 4.109).

Figure 4.105: Multiple sign posts on the outside of a curve

Source: Courtesy of DPTI and CfRS.

Figure 4.106: Non-frangible fencing

Figure 4.107: Non-frangible pedestrian fencing

Note: Fixed footing and railing welded to post.

Figure 4.108: Placement of roadside objects on a curve

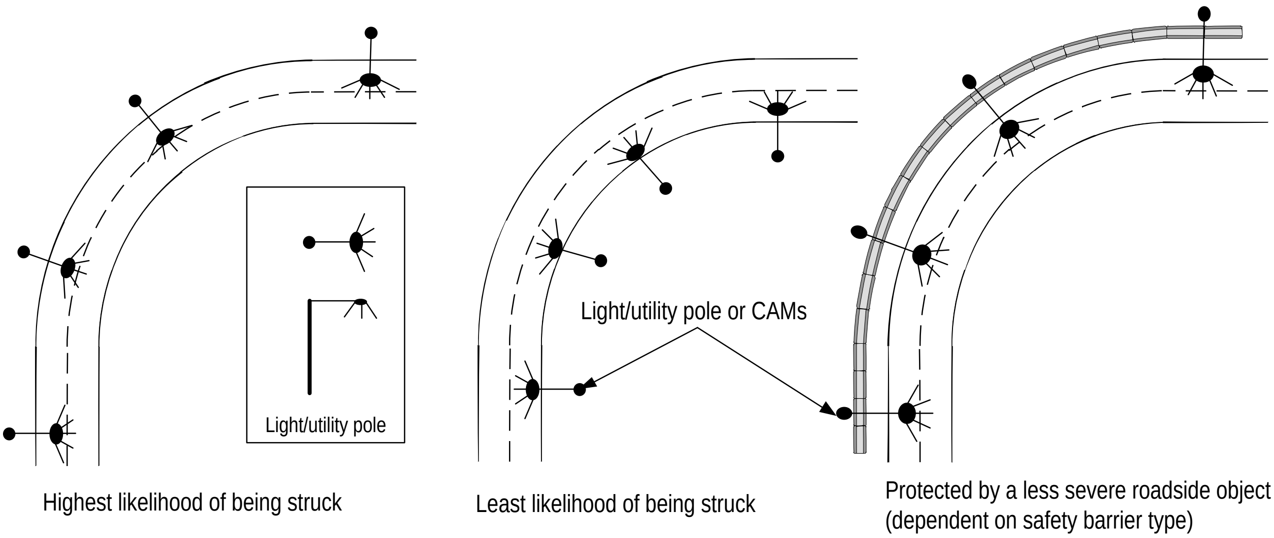
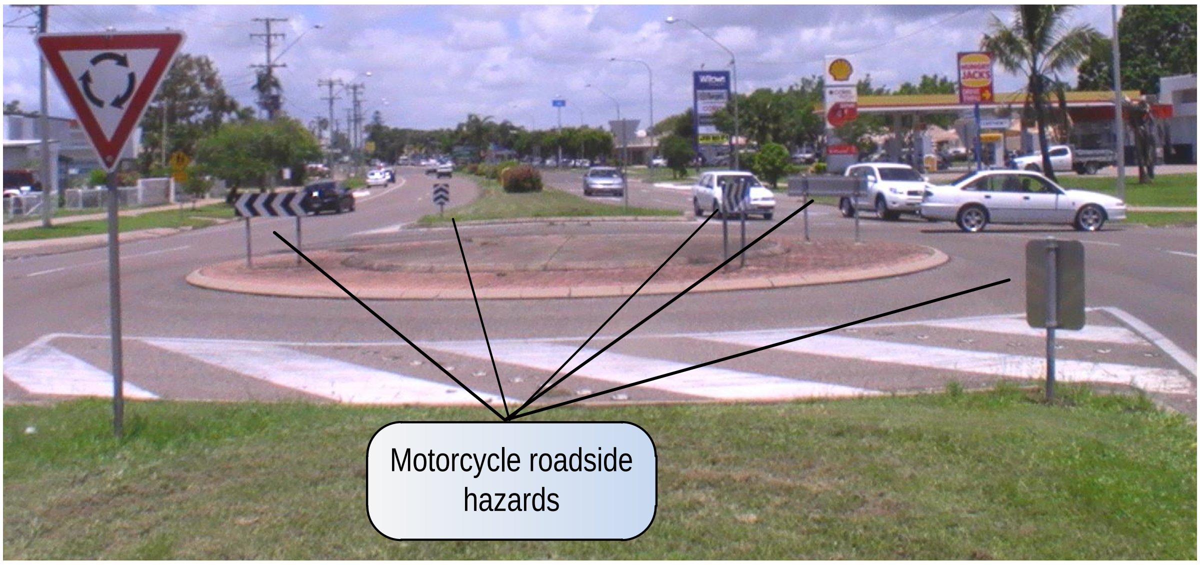


Figure 4.109: Motorcycle hazards at roundabout with standard signage layout



Source: Courtesy of TMR.

Sharp edges

Many roadside objects such as sign faces, guardrail delineators, guardrail post tops (Figure 4.110), guardrail end terminals (Figure 4.111) and fencing (Figure 4.112) have sharp edges which present a hazard to a motorcyclist. These sharp edges will concentrate impact forces and may penetrate the skin, even through protective clothing.

Figure 4.110: Sharp edges on guardrail post tops and metal delineators

Source: Department of Transport and Main Roads (2009).

Figure 4.111: End terminal (ET2000) with and without cover

Source: Department of Transport and Main Roads (2009).

Figure 4.112: Sharp edges on pedestrian fencing

Sharp edges *Rounded edges*

Source: Motorcycle Safety Advisory Council (2014).

Safety barriers

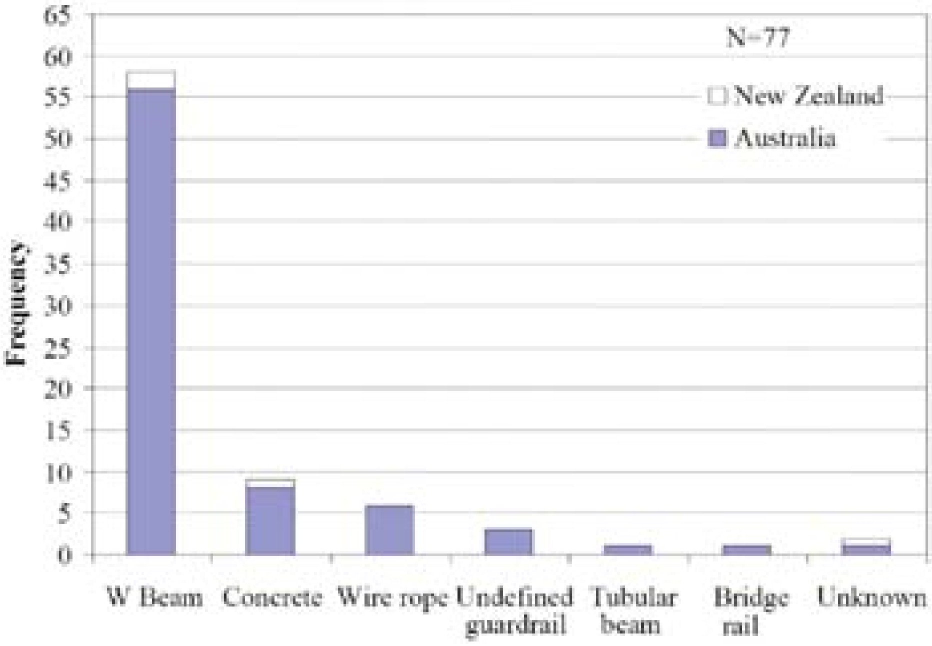
All safety barriers present as an impact hazard to motorcyclists in the event that they leave the carriageway. A recent study of motorcycle crashes with safety barriers in Australia and New Zealand (IRMRC 2010) demonstrated that more fatalities resulted from collisions with steel barrier posts than with a concrete or wire rope safety barrier (Figure 4.113).

The percentage of motorcycle fatalities and respective proportion of installed safety barrier are as follows:

- W-beams 72.7% (71.5% of safety barriers)
- concrete barrier 10.4% (8.6% of safety barriers)
- wire ropes 7.8% (15.9% of safety barriers).

The study also stated that the majority of barriers installed on curve roads, where most of the motorcycle crashes occurred, were of a more traditional W-beam design. Typically manufactures specifications restrict wire rope safety barriers being installed on small radius curves (typically < 200 m). The performance of wire rope safety barriers on small radius curves, which are the most likely zones a motorcyclists with strike a safety barrier, is not included in the reported data.

Figure 4.113: Fatalities by safety barrier type



Source: IRMRC (2010).

As 44% of motorcyclists (Bambach & Grzebieta 2014) slide along the road surface before striking a safety barrier, exposed guardrail posts (Figure 4.114) can prove to be especially dangerous as they are often hit by errant motorcyclists (Koch & Schueler 1987). Accident analysis has shown that severe injuries are sustained by two out of three motorcyclists that collide with guardrails (Domhan 1987) with the most dangerous feature of guardrail systems being the guardrail posts.

Figure 4.114: Unprotected guardrail posts on outside of curve

Motorcyclists thrown from their motorcycles onto the top of the guardrail can also be severely injured as a result of sliding along the exposed tops of posts. Motorcyclists hit the guardrail in an upright position in approximately 47% of crashes involving barriers (Bambach & Grzebieta 2014).

Motorcyclists thrown from their motorcycles onto the road surface in front of guardrail can slide into the posts. The posts may have sharp edges and corners which act to concentrate the impact forces and thus increase the severity of the injuries sustained (Ouellet 1982). Impacts with guardrail posts are about five times more severe than an average motorcycle accident (Pieribattesti & Lescure 1999).

In mountainous terrain, the presence of a safety barrier will prevent an injured errant motorcyclist that has left the roadway and is out of sight, from being left undetected. This may occur if a motorcyclist is trapped or injured and unable to climb an embankment to the roadway to seek help or be found.

Utility services

Utility services located in the shoulder or in the median are often non-frangible, small in surface area and have sharp edges (Figure 4.115). Utility services should ideally be underground, protected by a less severe roadside object, such as a safety barrier, and placed in a location where the likelihood of being struck is low.

Figure 4.115: Above ground water and gas pipes and meters

Drainage

Drainage infrastructure is non-frangible, has formed edges on barrier kerbs (Figure 4.116), raised hazards from the road surface (Figure 4.117), faces perpendicular to the through road (Figure 4.118), has unprotected drops (Figure 4.119) and, in some cases, has raised covers over drains (

Figure 4.120).

Figure 4.116: Concrete barrier kerb impact on helmet

Source: Department of Transport and Main Roads (2009).

Figure 4.117: Raised culvert wing and headwall

Figure 4.118: Culvert end wall and gully pit wall perpendicular to through road

Figure 4.119: Culvert drop in centre median

Figure 4.120: Raised drainage cover and wooden bollards

Source: Department of Transport and Main Roads (2009).

Natural environment and landscaping

Roadside objects such as trees (Figure 4.121) and large rocks are non-frangible and may have small surface areas and sharp edges. Embankments and cliffs may result in the motorcyclist falling from great heights. Cuttings may have rocks protruding from the surface (Figure 4.122) that have sharp edges and may result in rapid deceleration.

An errant motorcyclist and motorcycle that has slid down an embankment may not be visible from the road. This may result in them not being found in a timely manner to receive medical assistance.

Figure 4.121: Trees on roadside

Figure 4.122: Aggressive rock face on cutting

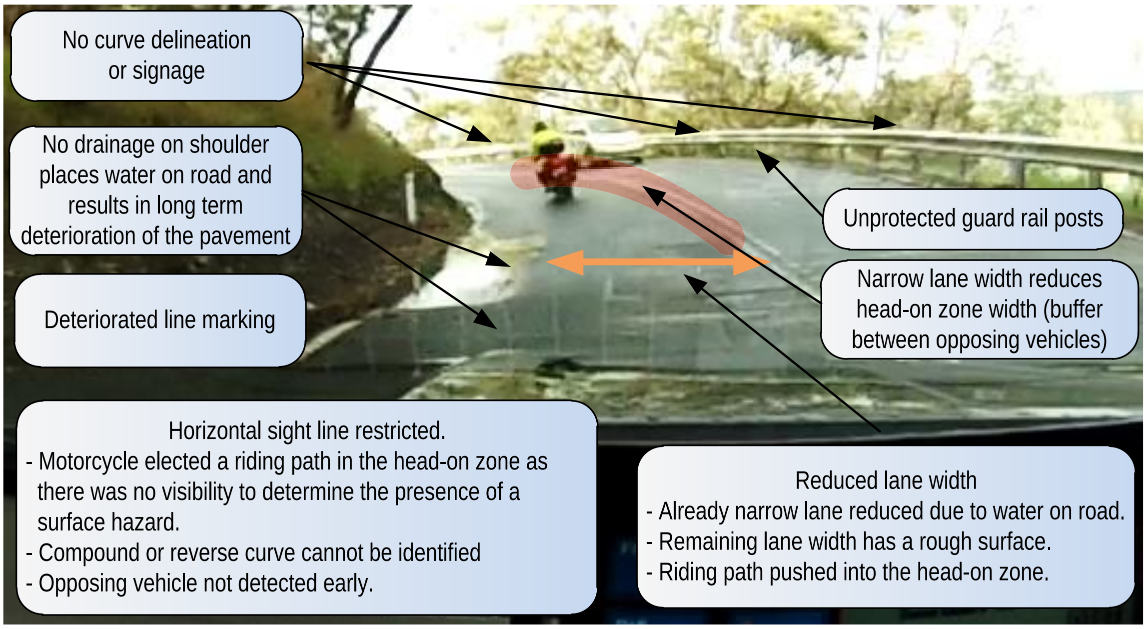
4.7 Total Crash Risk

The total crash risk for a motorcycle is the combination of the likelihood of a crash occurring and its resultant severity and is influenced by the number of unforgiving road infrastructure elements and the risk factors that are present as a result of either design or condition.

An example of a section of road where a concentration of non-motorcycle friendly road infrastructure elements are located and result in a high total crash risk is shown in Figure 4.123. The concentration of a number of crash likelihood and severity elements increases the crash risk.

If the road surface in Figure 4.123 was in perfect condition, the lanes wider, appropriate curve delineation signage including CAMs were present, it is possible that the likelihood of a crash may be somewhat lower. If the safety barrier had been set back from the edge of the lane and the shoulder was sealed, the severity may be further reduced, as would also be the case had the steel posts been fitted with a motorcycle/motorcyclist-friendly under-rail.

Figure 4.123: Total crash risk, concentration of non-motorcycle friendly road infrastructure elements



4.7.1 Crash Likelihood

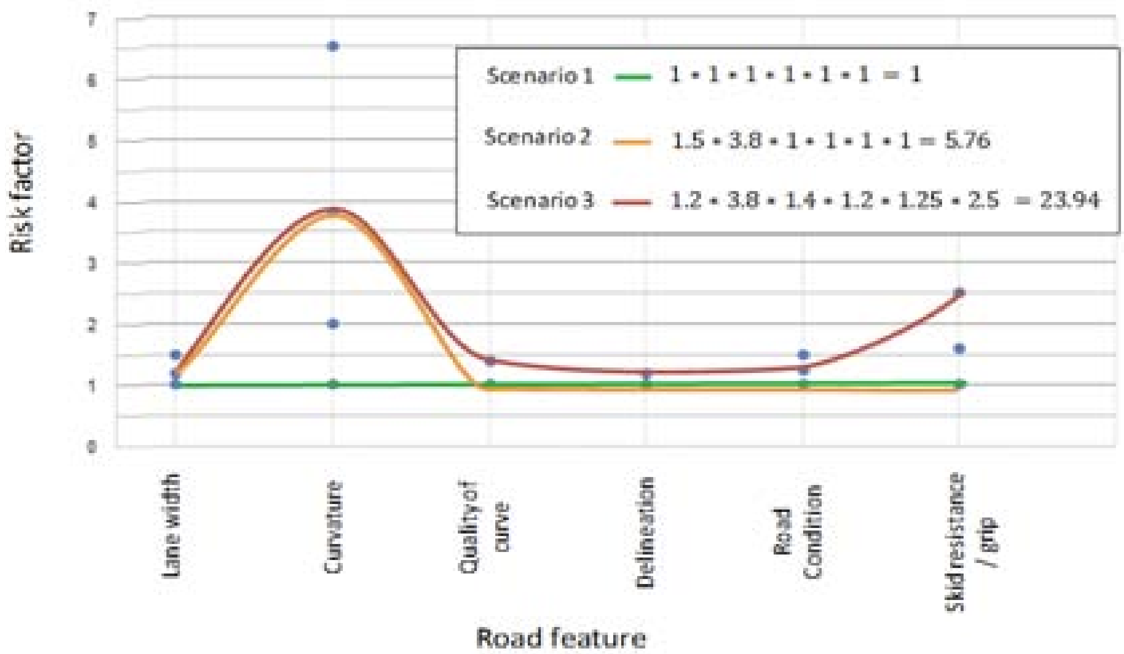
The likelihood of a crash occurring is influenced by the presence and condition of unforgiving road infrastructure elements (Section 4.4 and Section 4.5) i.e. a road section with a single unforgiving element will result in a lower crash likelihood than a road section with multiple unforgiving elements.

A practical example of this is shown in the three scenarios in Figure 4.124. The risk factors for each element in the graph are shown in Table 4.15. The following scenarios have different total crash likelihood risks due to the elements in each scenario having different characteristics and resulting risk factors:

- Scenario 1 is on a straight section of road with wide lanes, delineation and has good road condition and skid resistance.
- Scenarios 2 and 3 are on sharp curves with varying lane widths, delineation, road conditions and skid resistance.

The likelihood of a crash on the same curve in scenario 2 and 3 is significantly different. The likelihood of a crash in scenario 2 is less as the change in alignment is well delineated and signed and the lane is wide providing space between oncoming vehicles and the road is in good condition with good skid resistance to provide friction between the road surface and motorcycle tyre.

Figure 4.124: Crash likelihood risk scenarios



Notes:

- *The values for each scenario are the risk factors from Table 4.15.*
- *The total value represents the total risk for that combination of attributes.*
- *The curve plot does not represent the total risk, it shows the combination of risk according to the elements in the scenario.*

Table 4.15: Examples of crash likelihood factors

Road infrastructure element	Condition/category	Risk factor
Lane width	Wide (≥ 3.25 m)	1
	Medium (≥ 2.75 m to < 3.25 m)	1.2
	Narrow (≥ 0 m to < 2.75 m)	1.5
Curvature	Straight or gently curving	1
	Moderate curvature	2
	Sharp curve	3.8
	Very sharp	6.5
Quality of curve	Adequate	1
	Poor	1.4
	Not applicable	1
Delineation	Adequate	1
	Poor	1.2
Road condition	Good	1
	Medium	1.25
	Poor	1.5
Skid resistance/grip	Sealed – adequate	1
	Sealed – medium	1.6
	Sealed – poor	2.5

Note: Risk factor values are from AusRAP model version 3.3.

4.7.2 Crash Severity

The crash severity is influenced the number, condition and type of road infrastructure elements.

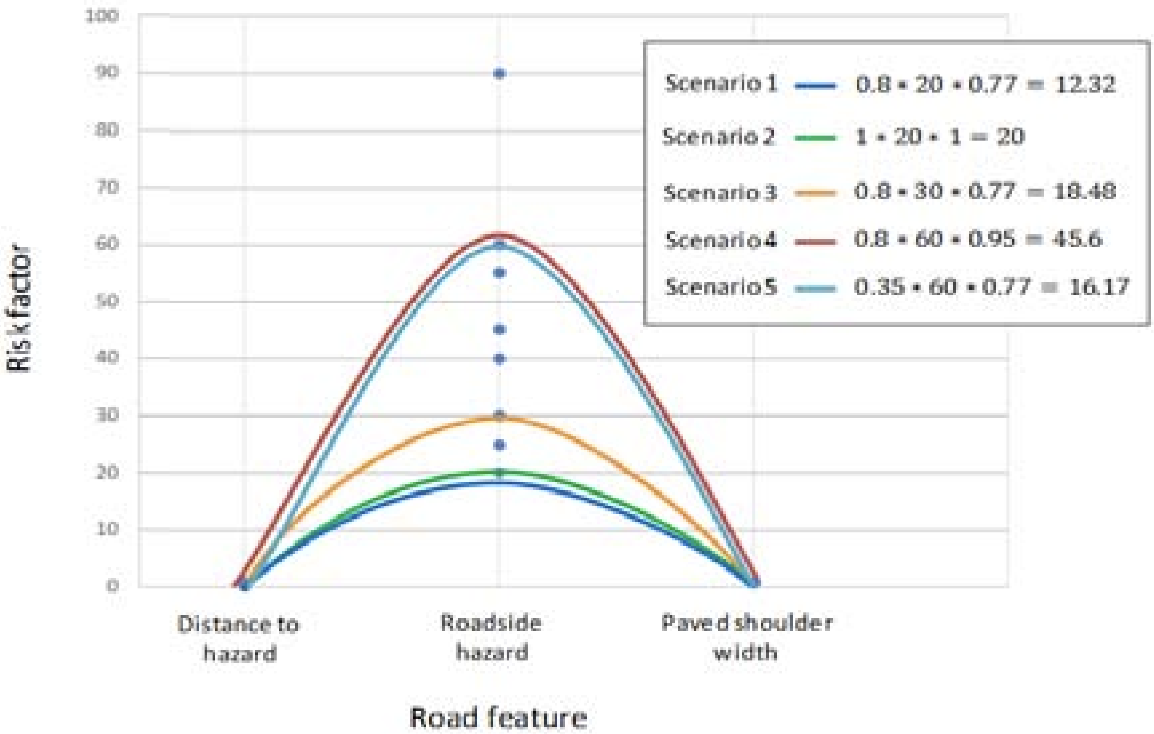
An example of this is shown in the four scenarios in Figure 4.125. The likelihood of a crash on the same curve in scenarios 2 and 3 is significantly different. The likelihood of a crash in scenario 2 is less as the change in alignment is well delineated and signed, the lane is wide and provides space between oncoming vehicles and the road is in good condition with good skid resistance to provide friction between the road surface and motorcycle tyre.

The risk factors for each element in the graph are shown in Table 4.16. The four scenarios have a different total crash severity risk due to the elements in each scenario having different characteristics and resulting risk factors:

- Scenario 1 has a motorcycle-friendly barrier set back from the carriageway and has a wide sealed shoulder.
- Scenario 2 has a motorcycle-friendly barrier on the edge of the through lane with no shoulder.
- Scenario 3 has a wire rope safety barrier set back from the through lane and has a wide sealed shoulder.
- Scenario 4 has a non-frangible sign post set back slightly from the through lane with a narrow sealed shoulder.
- Scenario 5 has a non-frangible sign post set back from the through lane with a wide sealed shoulder.

The crash severity risk in scenario 1 and 2 is significantly different due to the sealed pavement width and ability of a motorcycle to reduce collision speed before impact. The crash severity risk in scenario 3 and 4 is significantly different due to the sealed pavement width and ability of a motorcycle to reduce collision speed before impact.

Figure 4.125: Crash severity risk scenarios



Notes:

- *Risk factors are from Table 4.16.*
- *The total value represents the total risk for that combination of attributes.*
- *The curve plot does not represent the total risk, it shows the fluxion of risk according to the elements in the scenario.*

Table 4.16: Examples of crash severity factors

Road infrastructure element	Object, hazard or width	Rural
Distance to object/hazard	0 to < 1 m	1
	1 to < 5 m	0.8
	5 to < 10 m	0.35
	>= 10 m	0.1
Object/hazard	Safety barrier – metal mc friendly	20
	Safety barrier – concrete	25
	Frangible structure of building, safety barrier – wire rope, safety barrier – metal	30
	Upwards slope – > 75 degrees	40
	Downwards slope, upwards slope – 15 to 75 degrees	45
	Aggressive vertical face, deep drainage ditch	55
	Large boulders >= 20 cm high, non-frangible sign/post/pole >= 10 cm, non-frangible structure/bridge or building, tree > 10 cm, unprotected barrier end	60
	Cliff	90
Paved shoulder	Paved >= 2.4 m	0.77
	Paved 1 < Width < 2.4 m	0.83
	Paved 0 < Width<= 1 m	0.95
	None	1

Note: Risk factor values are from AusRAP model version 3.3.

5. Mitigation Measures

The report demonstrates that road infrastructure elements that contribute as a crash factor in motorcycle crash risk can be managed during the design, asset management and maintenance. The function of many existing roads in Australia and NZ have changed due to urban sprawl as a result motorcycling as a mode of commuting has increased in parallel to an increase in recreational riding. This places more motorcycles on the more roads during the week and on weekends, placing a higher focus on mitigation measures being required on existing roads through asset management programming and maintenance activities.

As demonstrated in Section 4.1 motorcyclists are a unique road user group that are influenced more adversely by road infrastructure compared to a passenger vehicle. Motorcyclists rely on road infrastructure elements to be designed or maintained to a higher level than what would traditionally be provided for passenger vehicles. The condition or design of a road infrastructure element may more negatively impact motorcycle crash risk than it would impact passenger vehicle crash risk. This may inadvertently be as a result of design practice or asset management and maintenance practices. As demonstrated in the crash analysis (Section 3) motorcycle crashes, irrespective of road type or hierarchy, are affected by the travel purpose (recreational riding on weekends and commuting during the week). Motorcycles and motorcyclists have unique needs and as a result have a higher reliance on the design and standard of road infrastructure to make safe decisions and maintain stability.

A number of motorcycle safety mitigation measures as identified in the literature review and outlined in Australian, New Zealand, European and American motorcycle safety publications are included within the recommended mitigation measures. Additionally road design and road safety engineering concepts, in particular the consideration of the resulting risk when a number of elements are aggregated at one location, as demonstrated in the AusRAP model, were also considered when identifying mitigation measures.

The primary recommended mitigation measure to reduce motorcycle crash risk, particularly the likelihood of a crash occurring, is to increase a practitioner's awareness of the road infrastructure element issues that affect motorcycle crash risk. It is considered that this would change practice in all road engineering disciplines, thus contributing towards lowering motorcycle crash risk.

A majority of the mitigation measures, given they are road infrastructure based, can be integrated into existing practice, programming and carried out under existing funding. This applies particularly to asset management and maintenance. A number of mitigation measures can also be applied at the road design stage, however the effectiveness would vary depending on the design being a greenfield or brownfield site, however it should be recognised that having sound guidance included in road design guidelines can be referred to by all road engineering disciplines. For this to come into fruition an update of the Austroads Guides for design, safety, asset management, pavement technology, traffic management and transport planning, as per the recommendations from the report would need be actioned.

Proactive Road Assessment Programs (RAPs) such as the Australian National Risk Assessment Model (ANRAM), AusRAP and iRAP are recommended to be used to identify motorcycle crash risk. A motorcycle specific road safety audit (M-RSA), as developed by ARRB Group can be undertaken to identify high risk locations for priority action and motorcycle-specific treatment recommendations can be provided. Treatment recommendations consider a hierarchy of control and if the treatment is reducing the likelihood or severity of a crash.

5.1 Mitigation Measures and Current Practice

The key road infrastructure elements that will reduce motorcycle crash risk are outlined in the various practices guides across Australia and New Zealand.

The emphasis on the standard, or warrants to trigger or justify the level that a road infrastructure element should be designed to, or maintained at, to cater for motorcycles is not conveyed through publications and therefore not yet part of daily consideration amongst practitioners. The following road infrastructure elements and guidance, when combined with the information provided in Section 4 (road infrastructure as a crash factor) will build the foundation for reducing motorcycle crashes where the road infrastructure is a crash factor:

- **Road alignment:** readable and consistent horizontal and vertical geometry. Horizontal geometry, particularly in the case of successive curves; should be consistent with radius, compound curves should be avoided (or clearly signed), and adverse crossfalls should not be used where a motorcycle's operating speed is likely to be high.
- **Sight distance:** clear visibility over a crest, through a curve, adequate sight lines between motorcyclists and other vehicles on curves and at intersections, to an object on the road, should be available, particularly on roads with narrow formations.
- **Cross-section:** lanes should be wide enough to provide width for safe riding path selection on curves, i.e. maintaining separation between vehicles, particularly between opposing traffic flows on undivided roads, allow for evasive action (this includes the width of the sealed shoulder). The shoulder width also provides space between stationary or parked vehicles and provides additional width for a motorcycle to recover, particularly on curves.
- **Overtaking provisions:** frequent, safe and legal passing opportunities for motorcyclists to pass vehicles that operate at a slower operating speed, particularly on mountainous or rolling terrain roads with narrow formations and poor sight distances.
- **Surface friction:** the wearing course should provide an appropriate level of surface friction in wet and dry conditions to allow for braking, emergency braking, and side-friction when a motorcycle leans on curves and turns and is required to brake and accelerate at intersections. This includes the friction of pavement markings and metal surfaces such as service covers and tram/train tracks.
- **Surface condition:** the road surface should be smooth, consistent and predictable. This includes not having changes in surface friction, delamination, potholes, water pooling or flowing on the surface, rutting, corrugations and depressions from surface covers or tram/train tracks.
- **Intersection type, control and turn provisions:** intersections have different risks for motorcycles, these are dependent on type. This requires acknowledgement of the risks for the various intersection types and providing road infrastructure outside of the existing warrants (i.e. AADT, turn volumes) such as signalised intersection control, turn provisions and clear identification of the intersection for all road users from all approaches with lighting, signage and delineation.
- **Intersection location:** intersections that are located on a curve, either side of a crest or are on a straight and inconspicuous (i.e. rural areas due to cuttings, urban area signage, buildings, and poles) should be clearly identified through signage or pavement markings.
- **Intersection sight distance:** sight lines between all road users on the through road and side road (including a vehicle approaching on a side road, before they reach the hold or stop line) should be available.
- **Roadside hazards:** the clear zone should be hazard free, any hazards that are deemed necessary (e.g. signage, guide posts, light poles) should be set back as far as practicable from the road shoulder, and be motorcyclist-friendly or protected by a less severe hazard such as a motorcycle-friendly safety barrier. Other hazards that do not provide a benefit to a road user with regard to enhancing the readability of the road or network (e.g. statues, water meters, utility poles) should not be in the clear zone, particularly on the outsides of curves or on the shoulder of a straight when the formation is narrow.

5.2 Implementation Strategies

5.2.1 Existing Practices

The implementation of mitigation measures to reduce both the likelihood of a crash occurring and reduce the severity in the event a crash does occur, can be undertaken predominantly by, but not limited to, practitioners in the road safety, road design, pavement design, asset management and maintenance, road engineering disciplines using existing practices and funding.

With an incorporation of the learnings from this report, in particular Section 4, collaboration and knowledge sharing between road engineering disciplines, the risk that road infrastructure presents as a motorcycle crash factor can be reduced and managed.

Over time motorcycle crash risk can be reduced through green and brownfield design (including pavement design), and management and maintenance of existing road infrastructure. This will complement mass action programs, and also ensure that any treatments implemented through mass action programs are maintained at the intended level.

Proactive risk assessments such as RAPs and M-RSA can contribute to identifying motorcycle crash risk locations as well as identify the safety benefits of mass action treatments. A M-RSA can provide more detailed information with regards to motorcycle crash risk and treatment options, such assessments should not be restricted to assessing existing roads, but also applied to treatment and road designs.

5.2.2 Proactive Risk Assessments

Proactive RAPs such as the ANRAM, AusRAP and iRAP can play an important role in identifying motorcycle crash risk on existing roads and review the motorcycle safety risk in new designs. Currently the motorcycle model is not active or reported in AusRAP assessments of state or national highways. The motorcycle model within AusRAP and ANRAM should be updated, based on the information within this report and activated and reported.

Motorcycle remedial mass action plans are active in a number of states, these identify motorcycle crash risk and implement treatments based on recommendations from road safety audits. Motorcycle remedial action plans and M-RSAs should focus on both reducing crash likelihood and crash severity. ARRB Group has developed a M-RSA methodology which identifies the highest motorcycle crash risk locations, by road infrastructure element and provides treatments to firstly reduce the likelihood of a motorcycle crash occurring and then reduce crash severity.

A number of safety issues that were identified in M-RSAs conducted by ARRB Group are shown in Table 5.1. These issues have been provided along with suggested treatments in accordance with a hierarchy of approach and the relevant Safe System pillar, the safe roads pillar, are all road infrastructure treatments. This table provide treatments that are likely to greatly reduce motorcycle crash risk (elimination) to marginally reduce motorcycle crash risk (administrative control). Small reductions in motorcycle crash risk should not be dismissed, a number of administrative control treatments at one location can still significantly reduce motorcycle crash risk. A number of solutions could be placed in the table for the safe people or safe vehicle pillars however these are not infrastructure related and have not been included unless a road infrastructure solution could not be provided.

Table 5.1: Remedial treatments by hierarchy of control

Control method	Issue	Safe System pillar			
		Safe roads	Safe speeds	Safe people	Safe vehicles
Elimination Remove the hazard from the road and traffic environment	Roadside object – tree	Remove tree to provide a clear zone			
	Poor surface texture	Resurface the road			
	Sharp horizontal curve	Realignment of road			
	Right turn crashes at signalised intersection	Grade separation			
Substitution Replace one hazard with another, less severe and more controllable hazard	Roadside object – tree	Install safety barrier			
	Poor surface texture	High surface friction treatment, re-instate the surface friction			
	Reduce crash risk on curves	Improve horizontal sight distance			
	Right turn crashes at signalised intersection	Provide a dedicated right turn phase and right turn lane			
Engineering control – isolation Apply design modifications to minimise road user interaction with the hazard	Roadside object – tree	Provide a wider shoulder to allow for recovery			
	Poor surface texture	Repair localised surface texture defect			
	Reduce crash risk on curves	Provide wider lanes and shoulder on curve			
	Right turn crashes at signalised intersection	Right turn lane, sight lines			
Administrative control Provide warning/advice to seek appropriate behaviour	Roadside object – tree	Install warning signs	Reduce posted speed		
	Poor surface texture	Install warning signs	Reduce posted speed		
	Reduce crash risk on curves	Improve delineation and signage on curve	Reduce posted speed		
	Right turn crashes at signalised intersection	Ensure intersection has good delineation and advanced warning signage	Reduce posted speed		
Personal protective equipment Use equipment to protect road users from death/injury	Roadside object – tree			Helmets	ESC, ABS etc.
	Poor surface texture			Rider training	ESC, ABS etc.
	Reduce crash risk on curves			Rider training and education	ESC, ABS etc.
	Right turn crashes at signalised intersection			High visibility clothing	ESC, ABS etc.

Note: These are indicative issues and treatments. This table does not represent all road infrastructure motorcycle safety issues nor all the treatments for the issues identified in the table.

5.2.3 Motorcycle Specific Guidance for Practitioners

The review of the current Austroads Guides for design, safety, asset management, pavement technology, traffic management, asset management and transport planning identified there is very little guidance that will guide practitioners to cater for motorcycles. Indicating within the various guides that motorcycles are a unique road user, with unique needs, and providing guidance to cater for motorcycles will result in motorcycles being considered in engineering decisions. This will over time reduce the number of motorcycle crashes and the need for separate funding and motorcycle specific remedial action plans.

The Austroads Guide Series should consider the whole of life costs of a road, in particular those costs linked to motorcycle crash risk. Guidance in this space would be particularly advantageous to unify design, asset management, pavement design and maintenance contract/practice decisions. The whole-of-life cost savings could be improved if the existing available data, funding and knowledge is combined with a broader knowledge of the motorcycle crash risk issues and specific motorcycle crash risk information (AusRAP, ANRAM, MRSA) with regards to infrastructure amongst practitioners.

A review of the Austroads Guides and a list of recommendations is provided in Section 7.

5.3 Additional Treatments to Reduce Motorcycle Crash Risk

In addition to managing motorcycle crash risk through existing standards and practices the following solutions should also be considered. These treatments take into consideration the majority crash trends identified in the crash analysis (Section 3).

5.3.1 Mid-block Treatments

Motorcycles are generally not well catered for on low volume roads. To name a few influencing factors, low volume roads typically have rolling or mountainous terrain with a high percentage of horizontal curves and crests, narrow lanes, unsealed shoulders, poor drainage, poor surface condition and roadside hazards (Section 4.4, mid-block crash likelihood). Due to the nature of limited funding, asset management programming and maintenance practices these roads are seldom managed so as to reduce motorcycle crash risk. Changes in practice can maintain the road to the desired level and within the allocated funding whilst also reducing motorcycle crash risk.

The crash analysis indicated that the highest proportion of motorcycle crashes occurred on the mid-block. The proportion of motorcycle crashes on a curve, was higher compared to the proportion of crashes observed for vehicles on a curve during the recreational period.

As the proportion of crashes involving a motorcycle on curves was higher than the proportion of crashes involving only passenger vehicles on curves, targeted mitigation measures have been provided. The most common crash types on curves identified in the crash analysis were head-on crashes and run-off curve crashes. Improvements to the road surface (in particular re-surfacing) on curves, curve approaches and departures, improving and maintaining delineation and curve quality signage should be a focus of asset management programming and maintenance activities. Lane widening, wide centre line and sealed shoulder widening on curves would also be required. These treatments are applicable on all road types however higher order roads generally do not require the same level of intervention as lower volume roads.

A number of motorcycle specific warning signage schemes and standalone signs can be implemented to reduce motorcycle crash risk, these are outlined in Section 5.3.3.

5.3.2 Intersection Treatments

Motorcycles are susceptible to crashes at intersections, this may be due to not being seen by other motorists (looked but failed to see), feeling pressured to move through the intersection to avoid being struck from the rear, or the concentrating of braking, accelerating and turning on wearing courses with worn or contaminated surfaces (Section 4.5, intersection crash likelihood).

The crash analysis indicated that the highest proportion of motorcycle crashes at intersections were vehicle adjacent approach (thru-right), opposite approach (thru-right) and adjacent approach (thru-thru).

Increasing sightlines at intersections to allow for greater SISD and also allow a motorcyclist to identify a vehicle on the side road as it approaches the intersection (Figure 5.1), separating all movements at signalised intersections with designated right turn lanes, protecting turning motorcyclists (signalised and unsignalised) with channelised right and auxiliary left turn lanes will reduce motorcycle crash risk at intersections.

In the likely event that SISD or ASD are not able to be provided due to buildings or infrastructure in an, urban environment, or high cost earth works in the rural environment, alternative treatments to traditional warning signage such as intersection ahead pavement markings or vehicle activated signs (Figure 5.2) could be used.

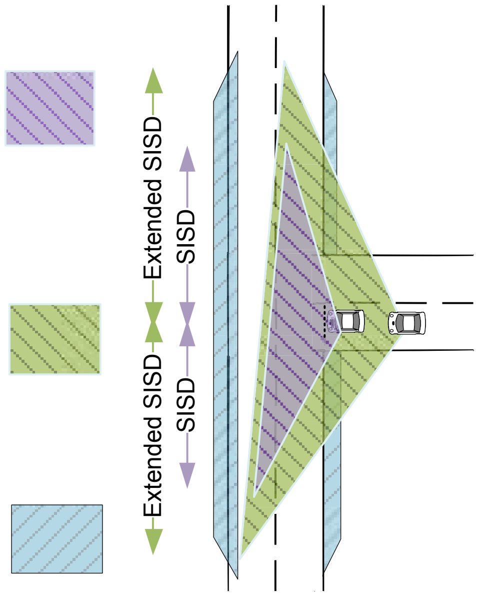
Motorcyclists are vulnerable to being struck from behind when stationary at the rear of a queue or within the queue at an intersection, particularly at urban intersections. Currently some jurisdictions allow lane filtering allowing motorcyclists to filter through the queue, however the lane width and position of other vehicles does not always guarantee a motorcycle can manoeuvre to the front of the queue. Providing designated motorcycle lanes at intersections will allow motorcyclists to move to the front of the queue, reducing the likelihood of rear-end crashes and sideswipe crashes whilst turning (Figure 5.3).

Figure 5.1: Safe intersection sight distance to approaching vehicles and manoeuvring width

Existing practice – The parameters considered in existing guidance for SISD, even when designed to provide the longest distance for a passenger vehicle it does not provide a long enough distance to cater for the non-conspicuous nature of motorcycles and the likelihood of not being identified by a vehicle on the side road or the possible reductions in co-efficient of deceleration for motorcycles due to surface condition, surface hazards or a riders skill level

Proposed practice – SISD may need to be longer than the maximum distances outlined in the design guides, and allow a rider to see a vehicle approaching on the side road. The additional sight distance and view to an approaching vehicle will allow a rider to identify an approaching vehicle and reduce speed in anticipation of not being identified and being able to stop before the conflict point. It will also provide additional stopping distance to allow for varying road conditions, hazards and rider skill and braking abilities.

Proposed practice – Provide manoeuvring widths to avoid a collision. Provide a wide shoulder (T-intersection) and widen lane/s.



Notes:

- *The diagram is also applicable to cross intersections.*
- *An increase in SISD may encourage higher turning speeds from the side road, this should be controlled e.g. channelisation, stop provision or signals.*

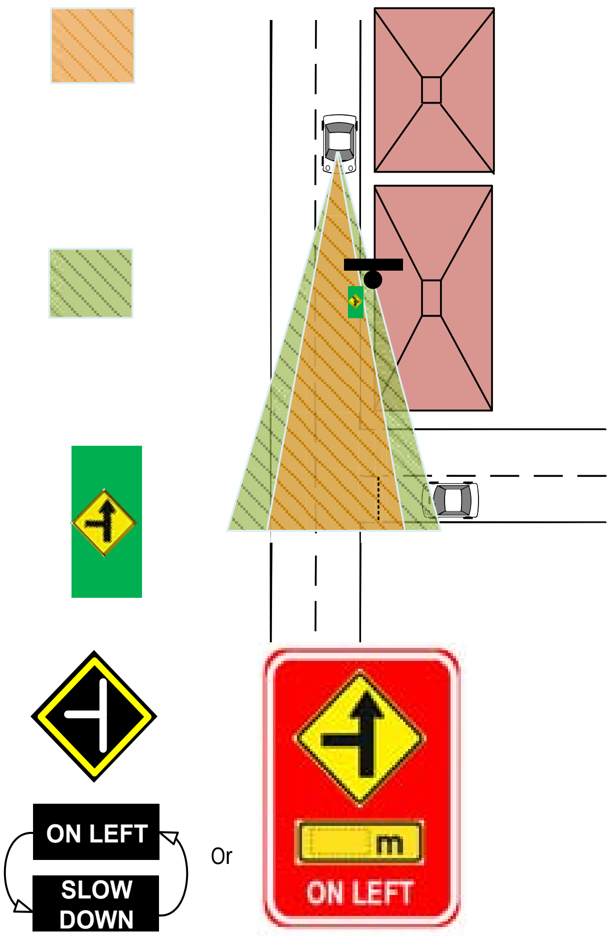
Figure 5.2: Safe intersection sight distance alternate treatments

Existing practice – SISD sight lines from the hold line. SISD does not factor in the non-conspicuous nature of motorcycles and the likelihood of not being identified by a vehicle on the side road or the possible reductions in co-efficient of deceleration for motorcycles due to surface condition, surface hazards or a rider skill level.

Proposed practice – SISD sight lines from side road approach. Additional sight distance will allow a rider to identify an approaching vehicle and reduce speed in anticipation of not being identified and being able to stop before the conflict point. It will also provide additional stopping distance to allow for varying road conditions, hazards and rider skill and braking abilities.

Proposed treatment – use pavement marking to clearly identify a side road on the left in urban areas with cluttered signage or rural areas with restricted sightlines. Pavement marking should only be used if a high surface friction paint is used and maintained. The pavement marking should only take up 1/3 of the lane width and be close to the shoulder. This would require considerable performance trials prior to being used.

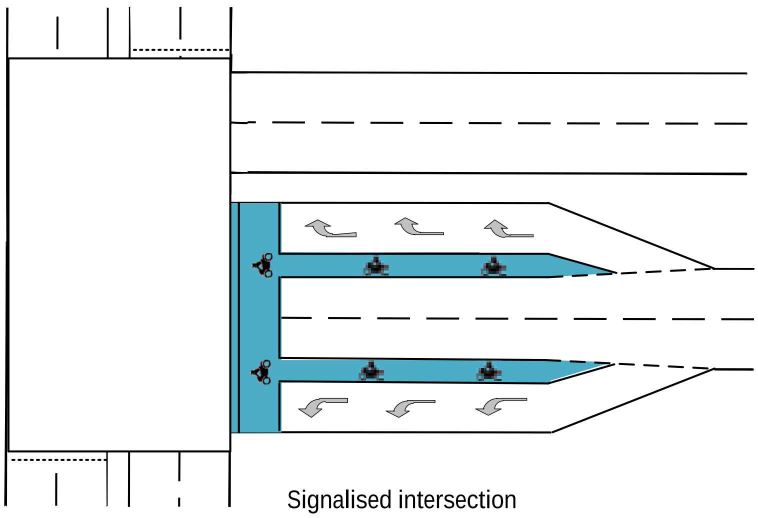
Proposed treatment – use vehicle activated signs or special warning signs to clearly identify a side road on the left in urban areas or rural areas with restricted sightlines.



Notes:

- *A combination of pavement marking and signage may be applicable in some situations.*
- *Diagram also applicable to cross-intersections.*

Figure 5.3: Motorcycle lanes at signalised intersections



Notes:

- *Diagram also applicable to all legs and to cross-intersections.*
- *This lane may also be able to be used by cyclists. Further considerations should be made regarding this.*

5.3.3 Motorcycle Specific Signage

Motorcycle specific warning signage may be an effective treatment on rural roads. These signs would raise awareness of the dangers the road may present to motorcyclists and also alert other vehicle drivers to be aware of motorcycles on the route, particularly at intersections and on curves. The signs suggested here (with the exception of sign B in Figure 5.4) are conceptual special warning signs, they use standard warning signs within the special warning sign principles.

Consideration should be given to the installation location, post type used and existing sight lines when installing new signs on routes with high motorcycle numbers. Any new signs installed should integrate with any existing signage. This may result in some existing signage having to be relocated so the signs are not clustered and are far enough apart to be interpreted. However they should not be too far from a hazard so as the sign is ineffective.

Crash Zone Signage

The hazardous nature of the identified motorcycle black lengths should be highlighted to all road users, focusing on motorcycles. Motorcycle Crash Zone Signage (Figure 5.4) should be placed on the high risk sections of the roads identified. These signs should be used in moderation and on the highest risk sections only so as they remain effective.

Figure 5.4: Crash Zone motorcycle warning signage

Sign A

Sign B (Existing TMR sign)

Look-for-bikes signage

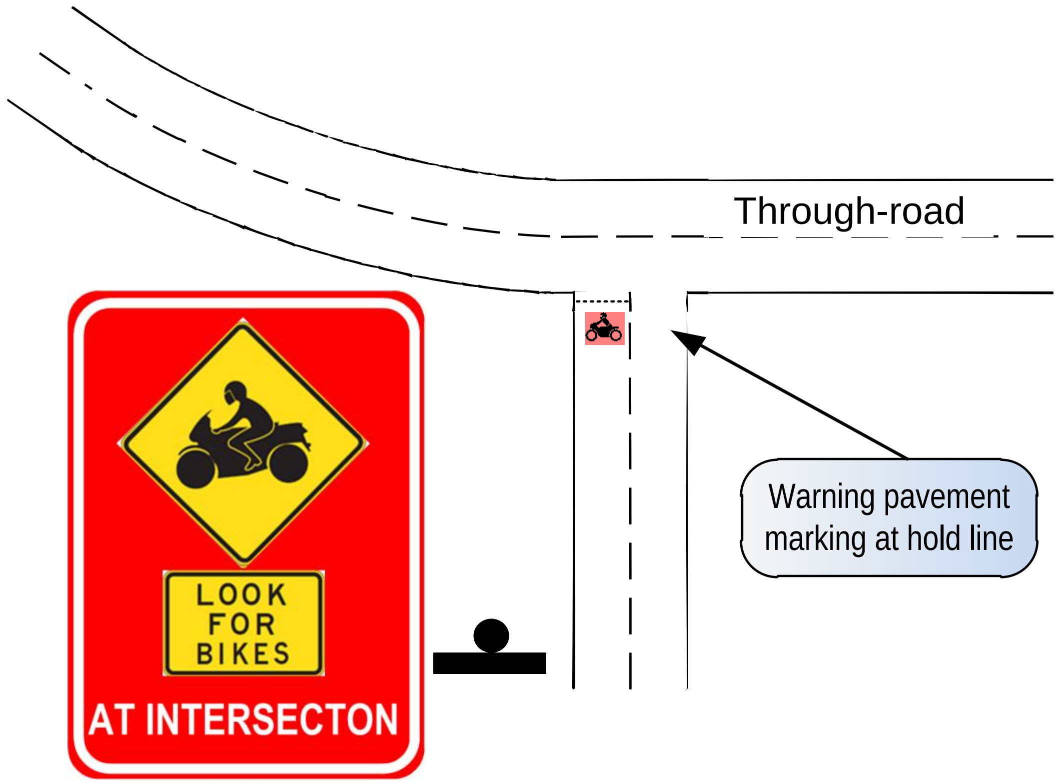
Look-for-bikes signage (Figure 5.5) should be provided along a road that has high motorcycle traffic, a history of motorcycle crashes or a road with a high motorcycle crash risk. This sign is currently used to alert vehicles that motorcycles are on the route. This is not to give them preferential treatment but to modify driver behaviour and scan the upcoming road for motorcycles. This is imperative as motorcycles are not easily identifiable due to their narrow envelope and often blend into the colours of the landscape. On long stretches of black length roads the Look-for-bikes sign should be placed to re-inforce that drivers should be aware of the presence of motorcycles.

There are scenarios on a route where motorists should be more alert and aware of motorcycle traffic. These situations are:

- at intersections where two roads with significant traffic volumes meet or where a side road meets a through road with high motorcycle traffic however the SISD is not met (Figure 5.6)
- on midblock sections where the lane or formation width is narrow (including shoulder) and sight lines around curves are restricted. Examples of signage are shown in Figure 5.7 on long sections of road with narrow widths, sign A would be placed at the beginning of the section and sign B would be used as a repeater. For short lengths of significantly narrow lanes or formation sign B could be used.

Figure 5.5: Motorcycle Awareness – motorcycle warning signage

Figure 5.6: Rural Intersection – motorcycle warning signage and pavement marking on side road



Notes:

- *Diagram also applicable to cross-intersections.*
- *High surface friction paint or coloured asphalt to be used.*
- *The symbol at the hold line is conceptual and would need to be interpreted as a 'look for motorcycles on the through lane', not as a head start area for motorcycles.*
- *It may not be necessary to use both signage and pavement marking e.g. signage may create clutter in urban areas, rural areas however may benefit from the combination of the warning sign and pavement marking.*

Figure 5.7: Narrow lane or formation – motorcycle warning signage

Sign A *Sign B*

Road condition signage

A road that is identified to be slippery during wet weather (poor surface texture) and due to debris on the road (plant matter, gravel and moss) should be treated in an effort to eliminate the hazard, however signage can be used to warn motorcyclists of the hazard in the interim.

The signs shown in Figure 5.8 should be used where foreign material such as vegetation, gravel or moss is known to be frequently on the road surface (sign A) and where the road surface, regardless of age and type, is potentially slippery during wet weather (sign B). Installation locations for sign B may be based on local knowledge and/or skid resistance test data.

Signage for potholes, pavement deterioration and the like would not be appropriate as these issues are generally transient, a whole route cannot be signed.

Figure 5.8: Road Condition – motorcycle warning signage

Sign A *Sign B*

5.3.4 Roadside Hazard Management

Roadside hazards that are aimed at reducing crash likelihood (roadside hazards Section 5.1) should be motorcycle-friendly. This may include signage, guide posts and light poles. Roadside hazards such as safety barriers may be in place as a substitute for a more severe hazard such as a cliff, tree, utility pole or traffic in the opposing lane. Each of these roadside hazards should adhere to the principles outlined in Section 4.6.

Roadside hazards that can be substituted with less severe alternatives should be. Some examples are sign posts (particularly CAMs), signage at intersections and roundabouts (particularly on medians, splitter islands and the central island), culverts with perpendicular faces should have a sloped face and the opening covered by a grate. Steel guardrail posts should be protected with under-rail and guardrail delineators should be plastic. A range of roadside hazard substitution treatments are shown in Figure 5.9 to Figure 5.17.

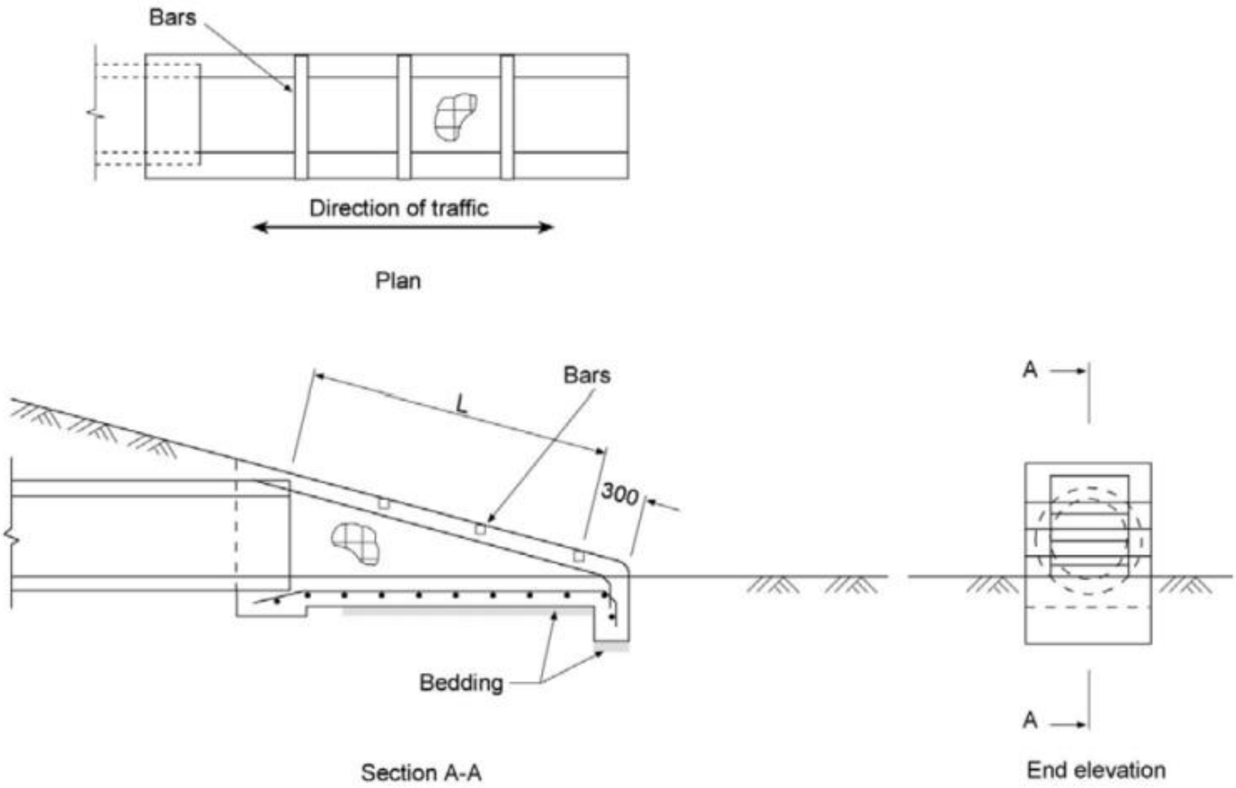
It is unlikely that all roadside hazards can be removed or replaced with a less severe alternative. It is however practical and feasible to address the safety issues outlined in Section 4.4 and Section 4.5, which contribute to the likelihood of a motorcycle crash occurring.

Figure 5.9: Flexible chevron alignment markers

Figure 5.10: Traversable grate over perpendicular culvert face

Note: If the grate bars are parallel to the travel direction, ensure that the width between bars will not allow a tyre of an errant motorcycle to become wedged.

Figure 5.11: Traversable grate over perpendicular culvert face schematic



Source: Austroads (2008).

Figure 5.12: Flexible intersection sign posts and sign faces (keep left sign)

Source: Department of Transport and Main Roads (2009).

Figure 5.13: Flexible guide posts

Source: Department of Transport and Main Roads (2009).

Figure 5.14: Sign post (a) and wire-rope barrier post (b) impact absorbing pads (see Section 1.4)

Source: (a) Department of Transport and Main Roads (2009); and (b) Ingal Civil (2015a).

Figure 5.15: Guardrail post caps and flexible delineators

Source: Department of Transport and Main Roads (2009).

Figure 5.16: Guardrail – ET2000 with and without cover over sharp edges

Source: Department of Transport and Main Roads (2009).

Figure 5.17: Guardrail – X350 cover over sharp edges

Source: Department of Transport and Main Roads (2009).

6. Stakeholder Consultation

6.1 Background

A key task involved consulting with key jurisdictional and motorcycle stakeholders. The purpose was to present the preliminary findings, to seek confirmation of the findings, to identify further areas that needed to be addressed, and to develop recommendations for changes to existing guidelines and practices, to address the needs of motorcyclists as a road user group.

The two-part consultative process involved representative jurisdictional and motorcyclists stakeholders:

- Responding to a questionnaire survey
- Participating in a workshop.

Issues discussed included:

- the findings of the literature review
- the results of the crash analysis
- the contributory and causal factors of motorcycle crashes
- how jurisdictions currently cater for motorcyclists
- the recommended changes to current guidelines and practices
- the cultural changes required to treat motorcyclists as an individual road user group.

6.2 Workshops and Consultations

A summary report containing the findings for the literature review, crash analysis and road infrastructure as a crash factor were sent along with survey questionnaires to 21 stakeholders throughout Australia and NZ on 24 April 2015. A total of 14 responses (approximately 70%) were received from stakeholders including Motorcycle Council of NSW, Main Roads Western Australia (MRWA), NZ Transport Agency (NZTA), iRAP, Motorcycle Riders Association ACT, Department of Planning, Transport and Infrastructure SA (DPTI), ACT Government, VicRoads and TMR. A list of representatives who completed the questionnaire and their responses are provided in Appendix B.1 and Appendix B.2 respectively.

A workshop was held on 7 May 2015 to discuss the survey results, proposed mitigation measures and changes to Austroads Guides. An invitation was sent to 21 stakeholders with a total of 10 participants attending. The workshop was carried out via teleconferencing to enable attendees from most states of Australia and from NZ to participate. The details of the attendees are provided in Appendix B.3.

A number of issues related to motorcyclist road infrastructure were identified from the questionnaire and workshop and are presented in the following sections.

6.3 Questionnaire Findings

The questionnaire outlined preliminary findings of the research undertaken and sought comment and feedback regarding:

- the preliminary findings including the literature review, the crash analysis, and the contributory and causal factors for both midblock and intersection crashes
- the range/scope, detail and quality of technical guidance currently available
- how, and the extent to which, motorcyclists are currently catered for in road design, asset management, and maintenance.

The issues identified and the comments received have been summarised in the following sections with the detailed questionnaire responses provided in Appendix B.2.

6.3.1 Comments on Preliminary Findings

The general responses confirmed the preliminary findings. The key issues raised from the questionnaire survey, including those in relation to the preliminary findings, were:

- Other research has shown a high number of single vehicle midblock-on-straight crashes.
- Further research is suggested to better define personal and collective risk.
- To what extent are overtaking manoeuvres an issue and are median treatments are a suitable treatment option?
- The crash analysis results were similar to a comprehensive crash analysis of motorcycle crashes in WA.
- The higher ratios for commuting multiple vehicle crashes at roundabouts in Qld and SA relative to NZ and single vehicle crashes are noted and need further investigation.
- Recent research undertaken by CARRS-Q examined unreported crashes. The results indicated that police crash data significantly under-reports hospitalisation crashes for motorcyclists.

6.3.2 Midblock Crash Likelihood

The issues raised from the questionnaire survey regarding the contributory and causal factors identified for midblock sections of road include:

Sight distance

- It was felt that aggressive trimming of vegetation back for the edge of the road is required to improve visibility through corners and approaches to intersections, and accordingly, education of maintenance staff is required.

Road alignment

- There is still a belief that motorcyclists do not use the full width of the lane when navigating a horizontal curve, however, the report has shown that this belief is not correct.
- The underlying principle of refraining from designing straight roads, in order to keep drivers occupied and alert, seems to be inconsistent with safety for motorcyclists. This should however be considered in context, not all curves are hazardous to motorcyclists. A single well designed curve with large radii, adequate lane width and surface friction presents a much lower crash risk than a series of small radius curves with narrow lane width and poor surface friction.
- In WA there have been many rural single vehicle fatalities where motorcyclists have failed to negotiate a medium or high speed bend and run wide and off the road. On close inspection it has been observed that the angle of superelevation at these locations tapers off towards the edge of seal. Some of these locations were right hand bends that had been treated with a seal widening. The widened perimeter often has less (or no) superelevation. This is significant as a motorcyclist already struggling to reduce their radius of turn will find it even harder when riding across the outer edge of a road if it has a reduced superelevation.

Travel period and traffic volume

- A higher crash risk has been detected at peak times due to legal lane splitting (filtering) manoeuvres.

Travel lane surface, conditions and hazards

- Seal joints between surfacing runs should be located well before a curve or braking area to give a motorcyclist an opportunity to react/respond appropriately.
- There is a key role for asset management practitioners to keep lanes free of hazards and debris and also to ensure appropriate skid resistance (grip) is provided, particularly at high risk locations (curves and junction approaches). Worn/polished inspection covers provide limited grip and cause problems in the vehicle path and in braking zones.
- The ACT concurs that debris on road, whether it be loose material or plant material, is a hazard to motorcyclists. Regular road sweeping, pruning of vegetation, sealing of adjoining roadways/driveways, and education regarding asset management practices can address this issue.
- Rutting, shoving and other deformities are more prevalent after rain or the cold ACT winter weather and sometimes result from constant heavy vehicle traffic. The deformities can be very unsettling for motorcycles, particularly if located mid-corner. More education for asset management practitioners would help.
- Delineation devices such as pavement blocks, raised pavement markers, Swarflex lane dividers and Vibraline can destabilise a motorcycle. Their use should be limited to areas unlikely to be impacted by a motorcycle.

Shoulder surface hazards

- Unsealed shoulders are hazardous to motorcyclists. Sealing the shoulder to the face of a safety barrier increases potential recovery space.

Formation width

- Wide lanes provide separating between opposing traffic lanes and to position him or herself at extremities of lane to maximise sightlines and/or entry/exit speed. Some form of separation is also important to reduce head-on crashes, these may be in the form of a flush median (urban) or wide centreline (rural).
- There is a limit to the effectiveness of wider lanes as it may encourage higher operating speeds.
- Sealed shoulders improve safety allowing space for recovery, however, if the shoulder is unsealed it can be hazardous to motorcyclists.
- The ACT Government has been introducing on-road bicycle lanes in more recent years, which often has the effect of reducing lane width for remaining vehicles, including motorcyclists, and has the knock-on effect of reducing buffer zones.

Signage and delineation

- Vehicle activated signs have been reasonably effective particularly in the UK, where approach speeds are inappropriate at bends or at village gateways.
- Whilst it is acknowledged that informative road signage can assist all road users, excessive road signage can distract or confuse motorcyclists and more significantly can become an additional roadside hazard. This is particularly the case in the urban areas of the ACT, where opinion was expressed that there is a plethora of non-road safety signage.

Curve quality

- Posts should be frangible.
- Chevron alignment markers (CAMs) should not be substituted with hazard markers.

Average speed and overtaking provisions

- It was agreed that there are average speed differences between passenger vehicles and motorcyclists. That being that motorcycles have a higher average speed and becoming queued behind slower moving vehicles.

Roadworks

- High standards are not always maintained at long term roadworks by agencies, particularly within the utilities industry.
- Appropriate signage of roadworks is important. Temporary signage must also be positioned appropriately to allow motorcyclists time to respond to the messages.
- Loose aggregate is often left on newly chip sealed sections of road and not always monitored or promptly swept up. Aggregate that results from a new sprayed seal should initially be monitored and swept at frequent intervals. After the seal has settled a secondary check should be undertaken and sweeping done if required.

Combination of factors

- It was agreed that when number of safety issues co-exist at one location the motorcycle crash risk exponentially increases.

Safety barriers

- It was suggested that in the ACT, the design of barriers is an area where motorcyclists are not adequately considered, or perhaps the cost of motorcycle-friendly barriers is deemed too expensive. The installation of rub-rails is an example of a treatment that improves barriers for motorcyclists in the event of a crash, but there are none currently installed in the ACT.
- All types of roadside safety barriers are likely to cause serious injury to a motorcyclist. When specifying roadside safety barriers the ‘no barrier option’ and barriers with motorcycle friendly features should be considered in the analysis.
- Recent research by Grzebieta et al. (2010) has demonstrated the benefits for appropriately designed road safety barrier systems to reduce motorcyclist injury and improve safety outcomes. Addition of motorcyclist protection systems, whether continuous (rub rails) or discontinuous (post buffers) will depend on the road safety barrier system. This is not well covered in the road safety barrier standard (AS/NZS 3845-2015) but it is understood that this is being addressed in the revision of the Standard.

Other

- Roadside furniture needs to be positioned to reduce the likelihood of an errant motorcyclist impacting it. Lighting poles should be positioned away from the kerb and the number of poles and posts can be minimised by mounting several signs on the one pole or post.
- Supporting structures for traffic signal lanterns should be designed so the structure is positioned away from the roadway.
- Speed humps and raised platforms need to be well delineated so they do not come as a surprise to a motorcyclist.
- It was held that there are many hazards within the road reserve which do not present serious harm to the motorist, but can be a significant potential hazard to motorcyclists. Placement, visibility and treatment of these potential hazards can considerably reduce the likelihood or effect of colliding with the hazard. For example, it was advised that in WA there have been fatalities where motorcyclists strike the nose of raised median islands. Many of these instances occurred during low light conditions. It is considered by improving the visibility of the leading edge of raised median islands, e.g. with high visibility/retro-reflective paint, that many of these incidents could be prevented. This is particularly relevant in unlit locations where delineation is not complete. Alternatively, painted (not raised) islands could be recommended where a raised island is not imperative.
- Modern LED road lighting is considered a significant improvement over current high pressure sodium or mercury vapour luminaires. Appropriate lighting design to achieve good levels of illuminance and uniformity are important.

6.3.3 Intersection Crash Likelihood

The key issues raised from the questionnaire survey regarding the contributory and causal factors identified for intersections include:

Visibility

- Due to the reduced effectiveness of motorcycle headlights, street lighting is an important consideration.

Intersection type

- Planting within the central median/centre island on roundabouts can obscure motorcyclists from other road users.
- In situations where construction costs are constrained or BCR needs to be positive then conversion of intersections to roundabouts can result in considerable slope change at the entry and exit transition points. Where funds are available the land around the roundabout is re-levelled so that transition crossfalls are reconstructed on all approach and exit points.
- The deflection design for roundabouts is for passenger vehicles, not for motorcycles. There are no design standards to ensure deflection for motorcycles.
- Kerbed or raised central islands in roundabouts are a risk to motorcyclists whose general travel line through the roundabout is straighter than that of a car or truck.
- T-intersections and cross-intersections have a high probability of high severity crashes for motorcyclists (and cars).
- Turn lanes should be encouraged at T-intersections and cross-intersections.
- It was advised that the ACT has a large number of roundabouts, some with adverse camber on the roundabout and their approaches. This not only affects the level of grip available, but also adds an extra complexity and distraction for motorcyclists.

Turning provisions

- Motorcyclists are exposed when stopped in the through lane to make a right or left turn.
- Motorcyclists may not be identified by oncoming traffic when turning right at unsignalised, right filter signalised intersections.
- Motorcyclists may not be seen when in the inside lane of a turn with dual turning lanes.

Horizontal geometry

- Due to the braking and handling characteristics of a motorcycle an intersection conflict point located on a curve (through road, slip lane or roundabout) is more difficult for a motorcycle to evaded and stay upright.

Advanced signage

- It was reported that much of the WA network was constructed under old standards. It is considered that many local roads have too many signs at intersections, many of which are poorly positioned due to utilisation of existing poles, and insufficient advance warning signage.
- While it is recognised that informative road signage can assist motorcyclists, excessive road signage can distract or confuse a motorcyclist and becomes an additional roadside hazard. It was felt that this is particularly the case in the urban areas of the ACT, where a plethora of non-road safety signage was apparent.

Line of sight

- Sight distances are not necessary calculated for motorcycles.
- Aggressive trimming back of vegetation from the edge of the road is recommended to improve visibility through approaches to intersections. Further education of asset management practitioners is required.
- It was reported that DPTI is commencing a trial of transverse line marking on the approach to a T-intersection, where line of sight is poor. Measurement of speeds of motorcycles and vehicles before and after the treatment will be undertaken.

Travel lane surface texture, condition, and hazards

- Debris on road, whether it be loose material or plant material, is a hazard to motorcyclists. Regular road sweeping, pruning of vegetation, sealing of adjoining roadways/driveways, and education regarding asset management and maintenance practices can address this issue.
- Pavement marking materials should have an appropriate level of skid resistance specified to reduce the likelihood of motorcycles skidding when braking or accelerating. There are specifications that exist requiring the addition of small nominal size aggregate to the line marking to improve skid resistance, usually transverse and 'other' markings, but this is rarely applied in practice. It is suggested that all line marking materials should have an as laid skid resistance of at least 55 BPN (i.e. measured by British Pendulum Tester) throughout the life of the marking.
- DPTI has developed an anti-skid (high skid resistance) road spray paint treatment which is still currently used, as well as trialling flexible guide and sign posts in conjunction with industry.

Carriageway width

- Preliminary comments were agreed to by stakeholders.

Lane filtering

- Whilst a lane filtering trial has commenced in the ACT (with the aim of reducing the prevalence of rear-end crashes), one component that would make filtering considerably safer and easier for motorcyclists at intersections is the introduction of forward stop boxes. However, this has not been implemented yet, due to limited funding being available.

6.3.4 Available Technical Guidance

The questionnaire sought information regarding what technical guidance is available in each state road agency. The following documents or comments were provided:

- Transport for NSW (2013) – *Making Roads More Motorcycle Friendly* (note: this document was reviewed as part of this research)
- NZTA (2012) – *Safer Journeys for Motorcycling on New Zealand Roads* (note: this document was reviewed as part of this research)
- Motorcycle Safety Advisory Council (2014) – *Making Roads Motorcycle Friendly* (note: this document was reviewed as part of this research)
- Institute of Highway Engineers (n.d.) UK – *Guidelines for Motorcycling*
- DPTI SA has considered motorcycles within other documented guidance in the past and is currently developing a dedicated technical guideline.

6.3.5 How Motorcyclists are Catered for in Design, Asset Management and Maintenance

Generally motorcyclists are not specifically catered for in asset management programs. However, New Zealand is investigating the development of an instrumented motorcycle and is examining current asset data collection techniques (including SCRIM and laser roughness) to determine whether more motorcycle-specific data can be derived.

DPTI SA applies the percentage of motorcyclists using a particular route to influence the type of safety barrier used i.e. the use of motorcycle-friendly barrier options such as underrun protection, crash cushions on wire rope fence posts etc.). DPTI has also conducted motorcycle specific road safety audits which identified high risk locations. This has enabled funding to be allocated to improve road and roadside features for motorcycling.

6.3.6 Raised Awareness from Preliminary Findings

Generally the preliminary findings from this project have raised awareness of the contributory and causal factors that influence the likelihood of a motorcycle crash, and particularly the compounding effects where a combination of factors exists. The findings were considered to be consistent with practical experience (e.g. ‘they bear out the experiences of local riders in ACT’).

6.4 Workshop Findings

6.4.1 Review of Project Findings

The project methodology, survey results, proposed mitigation measures and changes to Austroad Guides were presented at the workshop. Not unsurprisingly, the representatives from each state road agency or motorcycle council group tended to raise issues that were prevalent in their state. However, all of the issues raised reinforced the project findings.

The following is a summary of the key issues raised by the workshop participants:

- It is important that road users (and particularly motorcyclists) are able to identify compound curves and that appropriate signage and delineation is provided on rural roads.
- It is important that the use of CAMs and curve warning signage is consistent and provided when required, specifically for motorcycle routes, and in accordance with local requirements (e.g. as documented within the local MUTCD or similar).
- The aggregation of curves can be a problem for motorcyclists, as they may negotiate the first and second curve safely, however, mistakes are often made thereafter on consecutive curves.
- Frangible posts (for motorcyclists) should be used on curves and roundabouts.
- Training and education of the needs of, and issues for, motorcyclists are required by asset management practitioners.
- It is often difficult to analyse motorcycle crashes due to the lack of motorcycle traffic counts, crash data and the under-reporting of motorcycle crashes.
- Traffic counts may not include or detect motorcycles.
- VicRoads has produced a supplement to the Austroads *Guide to Road Design – Part 6: Roadside Design, Safety and Barriers* (Austroads 2009c). There are sections related to motorcycle safety which have been based on the superseded Austroads *Guide to Traffic Engineering Practice – Part 15: Motorcycle Safety* (Austroads 1999).
- End treatments for guardrail may be manufactured by a different company than the under-rail protection. The outcome may be non-compliant and lead to liability issues if guardrail does not perform properly.

- There is no operating speed model for motorcycles.
- There is a need for asset management and maintenance standards to encourage a high standard of work and to ensure roads are left in a good condition with no additional safety issues introduced on completion of the works.
- Crown transitions, crown shifts, lateral shift and sharp transitions (grade of the crown) should be positioned and completed so they are not a road surface hazard to motorcyclists.
- Roundabouts have been found to be hazardous to motorcyclists with a high number of single vehicle crashes occurring at these features. It is important that a motorcyclist can identify the presence of a roundabout, be able to correctly perceive the speed of circulating vehicles and to appropriately judge how fast to negotiate the roundabout. Frangible material should be used in the central island and mountable kerbing should be provided to prevent motorcycle foot pegs clipping the kerb.
- In some cases the central island of a roundabout is not circular but has changing curvature. This is difficult for motorcyclists to interpret when negotiating the curve.
- Roadside drainage – failure to maintain drains adequately increases the likelihood of material backing up onto to the carriageway creating a hazard to motorcyclists.
- Motorcycle crash reporting – if motorcycle crash barriers are not present and a motorcyclist loses control and runs off the road, other road users may be unaware of the crash or a motorcyclist may be difficult to locate in the event of a crash. A hit barrier identifies a crash has occurred. Alternative methods to detect a motorcyclist who has left the roadway, but is not visible, should be sought. This could include a barrier of some sort that is not obtrusive, and does not provide a safety barrier function however will be visibly and structurally altered if an errant motorcycle passes through it.
- Trampoline mesh barrier is prone to vandalism (using knives) and being melted in bush fires.
- It was reported that VicRoads had investigated different types of posts, poles and sign posts that may be more motorcycle-friendly. Experienced motorcyclists provided input into the study regarding the different products examined. They indicated they had a preference for plastic over metal materials.

6.4.2 Review of the Proposed Mitigation Measures

The working group unanimously agreed that the proposed mitigation measures (Section 5) were suitable. The message driven to the working group was that the mitigation measures are not only reactive however also intended to use existing asset management and maintenance practices to proactively improve infrastructure to reduce motorcycle crash risk.

Managing existing roads

Motorcycle needs should be catered for under existing asset management programs and funding.

Contractual governance in routine asset management and contracts, should focus on; maintaining sight lines, hazard free surfaces (intervention levels suitable for motorcycles) and signage placement and condition. Motorcycle specific maintenance guides and provisions as part of a contract.

Consideration to developing methods to use existing road data (pavement condition, AusRAP, crash history) to target sections of roads to be maintained at a higher standard than other sections.

Designing for motorcycles

Motorcycles should be identified as a road user group.

Motorcyclists should be considered in the design process, having guidance in all the Austroads Guides used for design, transport planning, pavement technology and asset management.

Values should be given in the Austroads Guides to justify expenditure or change of practice/design to cater for motorcycles. A motorcycle should also be a design vehicle e.g. pavement design; surface texture and performance in wet weather on intersection approaches, roundabouts and on sharp curves.

Hierarchy of control

Using a hierarchy of controls to manage motorcycle crash risk when maintaining existing roads and designing new roads was encouraged. It was agreed that providing guidance on how to reduce motorcycle crash risk through a variety of control measures would increase the likelihood of treatments being included in design and implemented in asset management and maintenance activities.

6.4.3 Recommended Changes to the Austroads Guides

The working group reviewed the proposed changes in the Austroads guide series. It was agreed that the Guides identify some basic information that may contribute towards a safer road environment for motorcyclists, however this is split amongst a number of different Guides and across the different guides for each road engineering discipline. This has the effect that no one Guide contains all the relevant information. There is no guidance given for the use of motorcycle specific warning or special warning signs. Guidance on the placement and installation requirements of service covers, tram/train lines (particularly on turning paths through intersections) was also not provided.

Guidance is available in a number of motorcycle safety guidelines/publications, however the principles and concepts in these guides is not provided within the various Austroads guide series. The references to motorcycles in the Austroads Guides tend to be general and practitioners are often not given specific advice on the most effective actions to take. Section 7 outlines the proposed c to the guides arising from the findings of this project.

Any current references to motorcycles within the Austroads guides only indicates that motorcyclists should be considered, however does not indicate what the considerations should be or what options should be considered to cater for motorcyclists. As a result a practitioner is not given clear guidance of how to cater for motorcyclists within the task they are completing, within their relevant road engineering discipline, i.e. road design, asset management, and pavement design etc.

The following Austroads Guides have been identified for updates as a result of this project:

- Guide to Road Design series:
  - Part 2: Design Considerations; inclusion of provisions for motorcyclists, commuting and recreational.
  - Part 3: Geometric Design; formation widths, sight distance, and horizontal alignment.
  - Part 4/4A and 4B: Intersection and roundabout design; intersection design (vertical/horizontal geometry on all turn paths, turn provisions and sight lines).
  - Part 5/5A and 5B: Drainage Design surface drainage (aquaplaning), design vehicle (inclusion of motorcycle), overtaking provisions, horizontal curve design and signage.
  - Part 6 and 6B: Roadside Design; safety and barriers; barrier types, curve radius selection for motorcycle safe barriers and clear zones.
- Guide to Road Safety series:
  - Part 6: Road Safety Audit; inclusion of more motorcycle specific guidance.
  - Part 9: Roadside Hazard Management; keeping vehicles on the road (shoulder width) and providing a forgiving roadside (motorcycle friendly barriers, sign and light posts).
- Guide to Pavement Technology series:
  - Part 3: Pavement Surfacing's; surface type (bitumen, asphalt and concrete) the skid resistance, texture, water spray and aquaplaning risk of each type to a motorcycle.
- Guide to Traffic Management series:
  - Part 3: Traffic Studies and Analysis; motorcycles to be surveyed and considered a unique road user group

  - Part 4: Network Management; update of information in user needs table (user considerations, clear signage and, surface, warrants for designated right turn signals, overtaking provisions)
  - Part 6: Intersections, Interchanges and Crossings; signal phasing (dedicated right turn), traffic detection.

- Guide to Asset Management series:
  - Part 3: Asset Strategies; investment strategy – asset use, Level of Service consideration, treatment prioritisation, new trigger values (motorcycle AADT, geometry, surface type, surface condition).

7. Austroads Guide Review

The following tables (Table 7.1 to Table 7.6) identify the parts of the Austroads Guides that have an influence on motorcycle crash risk and proposes a series of amendments aimed to reduce this risk. These influences may be during the concept and design phases or during the management and maintenance of a road.

It is recommended that to achieve a change in practice across all road engineering disciplines and to, over time, reduce motorcycle crash risk due to road infrastructure that the proposed actions outlined are considered for further inclusion in the relevant Austroads Guides.

The evidence base for a majority of the proposed actions for consideration are contained within this report, however some proposed actions will require further consideration by the relevant task force and further evidence based research.

7.1 Austroads Guide to Road Design, Guide Review

Table 7.1: Austroads Guide to Road Design – comments and proposed actions

Austroads Guide to Road Design			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
All parts of the Guide			
All parts of the Guide		The Guide to Road Design does not definitively outline guidance for greenfield or brownfield design nor a risk-based approach. Each design element is separated throughout Parts 1–8, guidance is not given on how to use a risk based design approach or achieve a 'safe design'/Safe System compliant design.	Provide further guidance on holistic design, inclusive of the effective combinations that design elements have on various road users (inclusive of motorcycles). An AusRAP style matrix could be used to demonstrate the resulting risk of a design.
Part 2: Design Considerations			
1 Design objectives	1	Motorcyclists have different characteristics compared to other road users. Vehicles, heavy vehicles, pedestrians and cyclists, public transport vehicles have been addressed as specific road users. Motorcyclists have not been included as a unique road user group.	Include an additional section e.g. (2.0) on providing for motorcyclists, identifying them as unique road users with different needs and characteristics compared to vehicles and other road users. This would include consideration of both commuting and recreational motorcyclists and outline high risk locations such as horizontal curves and intersections.

Austroads Guide to Road Design			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
1.1 Introduction	2	Motorcyclists have not been included as a separate user group.	Include motorcyclists as a user group.
2.4.2 Factors that influence design standards	13	This section refers to motorcycles as a motorised road user however no additional discussion is provided regarding how the operating characteristics of motorcycles may influence the road design. Discussion is provided for other road users.	Provide discussion regarding how the operating characteristics of motorcycles may influence the road design (e.g. provision of good sight distance, attention to curves, a clear predictable delineated roadway with a consistent road surface).
Part 3: Geometric Design			
3.0 Speed parameters	10	The operating speed model caters for passenger cars and does not reflect the operating speeds of motorcycles on various road types and environments. It is unclear if this caters for motorcycles, or on how to apply this to motorcycles. The operating speed of motorcycles may or may not affect the geometric design of an alignment however it may identify differences in operating speeds, which may alter how mitigation measures such as advanced warning signage, delineation, surface friction and drainage may be accounted for on curves.	Review the operating speed model to see if it reflects motorcycles. Research would need to be undertaken to determine an operating speed for motorcycles. Identify differences in speeds between motorcycles and vehicles. This may highlight where mitigation measures may be required to be implemented to cater for motorcyclists.
4.0 Cross-section	27	The cross-section width, particularly at horizontal curves, impacts on a motorcyclist. Although the vehicle is small relative to cars and trucks etc. it uses the full travel lane width when negotiating a horizontal curve. The width of the travel lane affects the sight distance and selected riding path a motorcyclist takes on a curve, the manoeuvring width around a hazard on the road surface, and the stopping distance and stability whilst braking when leant over on a curve, most importantly the distance (head-on zone) between opposing traffic streams on undivided roads. The shoulder width affects the likelihood of a motorcyclist recovering or reducing impact speed once the travel lane is left. These differences are not discussed in this section.	Provide discussion regarding how cross-section properties are important for motorcyclists with regards to moving a motorcycle away from the head-on zone, providing additional sight lines and riding path options, giving particular attention to formation width on horizontal curves. Further information provided in comments below for 7.9 Pavement widening on horizontal curves.
4.6.4 Kerb and channel	50	There is no mention of the effects of the conspicuity of kerbs (concrete on concrete pavement or kerbing at night) profile, height or location on motorcycles, especially at intersections and on curves. Barrier kerbs, if struck, may re-direct the path of a motorcycle or result in them losing control. It should also be noted that some states allow lane filtering, this adversely sees an increase in shoulders by motorcycles. An unfavourable barrier type is likely to snag a motorcycle foot peg whilst a motorcycle is using a reduced width to navigate between a vehicle and the kerb.	Provide guidance on the effects of kerbs on motorcycles, identify the risks and appropriate countermeasures such as lane/shoulder width and lighting or delineation.
4.10 On-street parking	83	No guidance is provided with regard to maintaining an adequate distance between the travel lane and parked vehicle. An opening vehicle door (parallel parking) or the front or rear of a car may enter the through lane during parking manoeuvres. Additional width between a parked vehicle and the through lane will grant a motorcycle additional time to identify and evade any part of a parked car entering the through lane.	Provide guidance on maintaining a 'buffer' between a parked car and the through lane. The buffer would be more critical in areas with high traffic volumes and/or roads with reduced lane widths. The width would vary dependent on the curve radius and possible motorcycle lean angles, this would need to be investigated further.

Austroads Guide to Road Design			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
5.0 Sight distance	99	Sufficient sight distance is crucial to motorcyclists. The consequence for a motorcyclist not having enough time to perceive and react to a hazardous situation is potentially severe. Therefore, it is important that attention be given to sight distance for motorcyclists, particularly on curves. Table 5.3 provides the coefficient of deceleration for different vehicle types, and different road surface types and conditions. There are no coefficients of deceleration for motorcycles provided in the table. Current practice is to adopt those for vehicles.	Investigate whether specific coefficient of deceleration values are required for motorcycles or whether the current values for vehicles are appropriate. This would enable the stopping sight distance to be calculated for motorcycles.
7.0 Horizontal alignment	133	The effects of various curve types, curve lengths, curve combinations, curve radius and frequency of curves and motorcycle crash risk is not discussed. Motorcycles have a higher crash risk on curves than passenger vehicles.	Provide guidance on horizontal curve design for motorcycles. Undertake research to define the risk factors per design element and provide guidance accordingly.
7.7.6 Rate of rotation	153	If the maximum rate of rotation on a curve is exceeded, a motorcyclist is at greater risk of losing control while negotiating the curve compared to other vehicles. This may be more prevalent on different road surfaces when wet. Foot pegs are susceptible to contacting the road surface on compound curves.	Provide guidance on rate of rotation maximum values for motorcycles. Undertake research to define the effects of the existing maximum rate of rotation values on motorcycles and provide guidance.
7.8 Curves with adverse crossfall	158	Adverse crossfall (camber) is hazardous as motorcycles rely on ‘grip’ between the road surface and tyre to maintain control when negotiating a curve. This is exacerbated by the motorcycle leaning even further due to the adverse camber. Table 7.10 gives minimum radius curves for various operating speeds for which adverse crossfall may be considered. The maximum side friction values used in this table are for all vehicle types. The motorcycle dynamics are different to other vehicles.	Undertake research to determine whether there is a need for a specific coefficient of side friction/curve radius combination specific to motorcycles. Provide guidance as required.
7.9 Pavement widening on horizontal curves	159	A wider lane and shoulder on curves allows a motorcyclist to select a safe riding path while also maintaining a buffer (head-on zone) to vehicles in the opposing lane (left hand curve) or the shoulder (right hand curve). It should be differentiated that this is not providing a lane wider 3.5 m as per the existing guidance for heavy vehicles, the discussion is around providing a wider formation than what might already be in place or than what is recommended based on road type and AADT on curves only, i.e. the straight may have a 0.5 m sealed shoulder, lane width of 3 m, the curve would benefit from a 1.0 m sealed shoulder and 3.3 m lane. No discussion is provided regarding the benefits of wider formations of curves for motorcyclists.	Provide discussion of the benefits of wider formations on curves for motorcyclists. Including of providing a wide centreline provide separation between opposing traffic. Wide sealed shoulders should also be provided to allow an errant motorcycle to recover or use the width to avoid a hazard in the through lane.
9.4 Overtaking lanes	191	Inadequate overtaking provisions may lead to unsafe overtaking manoeuvres, particularly when the average speed of a vehicle over a length of road is slower than the average speed of a motorcycle. This may be due to repeated and tight horizontal geometry. A motorcyclist sitting behind slower vehicle/vehicles may overtake at non-designated and unsafe locations.	Develop an operating speed model for motorcyclists as per the proposed action for 3.0 Speed Parameters. Pending on the findings, include guidance on the need for overtaking opportunities where there is an imbalance in average speeds for motorcycles and vehicles.

Austroads Guide to Road Design			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
Part 4: Intersection and Crossings – General			
1.6.1 Pavement markings and signs	4	There is no guidance on the skid resistant properties of pavement markings needed for motorcycles. Pavement markings located in braking, accelerating or turning locations will affect the stability of a motorcycle if they do not provide sufficient surface texture. The paint is not always durable, and deteriorates over time resulting in no night time delineation.	Provide guidance on the use of suitable pavement marking materials/paint.
1.6.2 Road lighting	5	There is no guidance on the effects lighting has on motorcycles, including the importance of clearly showing the layout, lane designation, presence of surface hazards and debris, surface texture, kerbing and roadside hazards at night.	Provide guidance on the use of lighting and the needs of motorcycles.
5.2 Design vehicles	26	The introduction of this section says 'The physical and operating characteristics of vehicles using the road control some specific elements in geometric design' however the characteristics of a motorcycle are not included.	Provide guidance on the special needs of motorcycles, make references to sections within the document that should be considered during the design process.
Not in Guide: Location of pavement marking and service pit covers	–	There is no guidance on the effects of the location of line marking, pavement markers or service pit cover locations on intersection approaches, departures and turning paths.	Provide guidance on the location of line marking, pavement markers or service pit cover locations on intersection approaches, departures and turning paths and the effects these have on turning motorcycles. This should also be provided in Parts 4A and 4B.
Part 4A: Unsignalised and Signalised Intersections			
3.2 Sight distance requirements for vehicles at intersections	15	The requirements and distances are provided for passenger vehicles only. There is no mention of the needs for motorcycles nor the vulnerability of motorcycles to multiple vehicle crashes at intersections (Section 3.7.6).	Review the co-efficient of deceleration values and determine if these are relevant for motorcycles, this should consider weather, pavement type and pavement life/condition. Provide guidance on the vulnerability of motorcycles at intersections, i.e. a passenger vehicle not seeing a motorcycle, a motorcycle having an increased stopping distance in the wet or dry when the road surface has poor surface texture or surface hazards such as pavement defects, a slippery linemarking or service pit cover. An increased sight distance will also provide a motorcyclist an opportunity to identify a vehicle and act accordingly before emergency braking is required. Investigate if the SISD should be increased to be measured from the approach to the hold line as opposed to the hold line, thus giving motorcyclists increased time to safely decelerate and avoid a collision. Provide guidance on the effects lane width may have on a motorcyclist avoiding a collision.

Austroads Guide to Road Design			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
4.8 Warrants for BA, AU and CH turn treatments	44	The warrants are based on passenger vehicle AADT and cater for the needs of passenger vehicles. The warrants are based on turning volumes and road user protection combined. Motorcycles are vulnerable, particularly when stored in a through lane to turn right or left. This vulnerability may also lead to a motorcyclist feeling pressure to make a turn quickly and not wait for a suitable gap to do so.	Include guidance for providing protected turn lanes to separate motorcycles from a through lane when stopped to turn. Warrants could be based on vehicle AADT, motorcycle AADT, sight distances, operating speed, percentage of heavy vehicles and crash history on the link.
Not in Guide: Skid resistance	–	There is no guidance on the skid resistance properties of pavement markings needed for motorcycles. Pavement markings located in braking, accelerating or turning locations will affect the stability of a motorcycle if they do not provide sufficient surface texture.	Provide guidance on the use of suitable pavement marking paint.
Not in Guide: Skid resistance	–	There is no guidance on the skid resistant or co-efficient of friction properties of a pavement type (asphalt mix, chip seal or concrete), including drainage properties and performance for motorcycles. This is crucial for a motorcycle turning through an intersection, especially one with an adverse crossfall.	Provide guidance on the use of suitable pavement and resulting surface performance.
Not in Guide: Motorcycle lanes and jump starts areas	–	Currently the road design standards do not consider providing motorcycle lanes and jump start areas at intersections. Currently this is informally allowed in some states by changes to legalise lane filtering.	Provide guidance on what situations to provide motorcycle lanes. Consideration should be given as to how these will be designed (particularly when interacting with turning or slip lanes) and should consider interaction/sharing with cyclists.
Part 4B: Roundabouts			
3 Sight distance	12	The requirements and distances are provided for passenger vehicles only. There is no mention of the needs for motorcycles nor the vulnerability of motorcycles at intersections. Higher speeds of motorcycles through roundabouts is also not considered (see entry geometry). Specific guidance is provided for trucks but not motorcycles. The importance of early identification of motorcycles by other road users is not highlighted.	Provide guidance on the complexities of motorcycle stopping distance, particularly with regard to stopping distances on curves (i.e. curve approaches or on the circulating carriageway). Provide guidance highlighting the importance of conspicuity of the presence and layout of the roundabout from the approaches. Research needs to be undertaken with regard to open or restricted sight lines and the effects they may have on motorcyclist behaviour i.e. the influence it has on motorcyclists acknowledging the need to yield or maintaining speed if entry geometry does not restrict motorcycle approach speeds.

Austroads Guide to Road Design			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
4.5 Entry geometry	21	Approach entry curve radius design guidance is provided for passenger vehicles. A motorcycle speed is not as effectively reduced by an entry radius as it is narrower than a vehicle and can effectively use the lane width to continue straight through the curve. This asks the question of sight distance requirements, and assumed approach speeds used to design for sight distance.	Research motorcycle speeds on various entry curve radii. Provide guidance on how to manage approach speeds of motorcycles or provide sight distance so as a motorcycle can adjust speed or yield to avoid a collision with a vehicle on the roundabout.
4.10.1 Crossfalls	43	There is no specific guidance to cater for motorcycles, however there is for heavy vehicles. However motorcycles may have to negotiate adverse crossfall, superelevated crossfall whilst passing through or turning on a roundabout. Motorcycle stability is reliant on consistent geometry and surface friction, this is not mentioned.	Provide guidance on how to design a roundabout that does not adversely affect motorcycles. This would include guidance on pavement type and performance in wet weather and the combined effects of surface friction and adverse and/or changing crossfalls/superelevation.
6 Pavement markings and signage	61	In Table 6.1 there is no guidance on the skid resistance properties of pavement markings needed for motorcycles. Pavement markings located in braking, accelerating or turning locations will affect the stability of a motorcycle if they do not provide sufficient surface texture.	Provide guidance on the use of suitable pavement marking paint.
Not in Guide: Surface friction/skid resistance	–	There is no guidance on the skid resistant or co-efficient of friction properties of a pavement type (asphalt mix, chip seal or concrete), including of drainage properties and performance for motorcycles. This is crucial for a motorcycle turning on the circulating carriageway, especially one with an adverse crossfall.	Provide guidance on the use of suitable pavement marking paint wearing course surface friction (focus on circulating carriageway), drainage and landscaping watering systems.
Not in Guide: Kerb delineation and profile	–	There is no mention of the effects of kerb conspicuousness (concrete on concrete pavement or kerbing at night) profile, height or location on motorcycles, especially at intersections and on curves (including curves on intersections, e.g. central island and kerbing on left turns). Barrier kerbs, if struck, may re-direct the path of a motorcycle or result in loss of control. It should also be noted that some states allow lane filtering, resulting in an increase number of motorcyclists using the shoulders. An unfavourable barrier type is likely to snag a motorcycle foot peg whilst a motorcycle is using a reduced width to navigate between a vehicle and the kerb. Guidance is provided for buses with regard to kerb height and type, however not for motorcycles.	Provide guidance on the effects of kerbs on motorcycles in Parts 4, 4A and 4B. Identify the risks and appropriate countermeasures such as lane/shoulder width and lighting or delineation.
Part 5: Drainage Design			
2.2 Road user considerations	7	This section contains the general needs of road users and specific mention of public transport vehicles, bicycles and pedestrians, however, there is no mention of motorcyclists. Water on the road surface is particularly hazardous to motorcyclists, having only two wheels in contact with the road surface. Water on the road may reduce the friction between the road surface and the motorcycle tyre which reduces stopping distance and side-friction. The importance of the location of drainage pits, pipes and other drainage structures in intersection design is discussed. The location of these is mentioned as a potential hazard to pedestrians and bicyclists. These can also be hazardous to motorcyclists.	Provide guidance regarding the impact of a wet road surface on motorcyclists. Include consideration of motorcyclists with regard to the location of drainage pits, pipes and other drainage structures at intersections.

Austroads Guide to Road Design			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
3.3.2 Skid resistance	16	In the surface drainage section, there is a sub-section on skid resistance. This section does not go into specific needs of road users, however, the consequence of poor skid resistance is significant to the safety motorcyclists.	Provide discussion regarding how poor skid resistance due to water on the road impacts on motorcyclists including tyre spray restricting vision, a motorcyclist changing riding path or evasive action when water on the road is identified, reducing or loss of friction between surface and tyres which in turn affects motorcycle stability when braking and cornering.
3.2.3 Aquaplaning potential	16	This section does not discuss how aquaplaning impacts specific road users, however, the consequence of water ponding on the road surface and aquaplaning is significant to the safety of motorcyclists.	Provide discussion regarding how aquaplaning impacts on motorcyclists.
Part 5A: Drainage – Road Surface, Networks, Basins and Subsurface			
4.0 Aquaplaning	33	This section explains how aquaplaning occurs and factors that influence aquaplaning. Aquaplaning is hazardous to all road users, however, it is particularly hazardous to motorcyclists. This needs to be highlighted.	Include discussion regarding how aquaplaning impacts on motorcyclists.
5.0 Kerbed drainage	54	This section discusses a range of items regarding the use of kerbed drainage. Under this section there is a sub-section on ‘non-motorised road users’ which outlines some of the key considerations for these road users when designing kerbed drainage. Consideration also needs to be given to the needs of motorcyclists, for example, the location of drainage pits near corners or braking areas and intersections, types of drainage pits, covers being a road surface hazard etc.	Include an additional sub-section to provide guidance on the design of kerbed drainage infrastructure on motorcyclists.
6.2.8 Road user considerations	100	This section discusses the requirements for the placement of access chamber covers for piped drainage networks for non-motorised road users. However, there is no mention of motorcyclists. Drainage manhole/access covers are a road surface hazard to motorcyclists.	Provide guidance regarding the placement of access chamber covers/manholes with respect to motorcyclists.
Part 6: Roadside Design, Safety and Barriers			
6.2 Factors considered in barrier selection	65	Motorcycles are considered throughout this section however, more detail could be provided regarding how certain features and types of barriers impact motorcyclists e.g. capping of posts, end treatments, types of underrun protection, vandalism/fire damage of mesh options etc. Photographs/illustrations showing suitable barriers for use along motorcycle routes would be beneficial.	Incorporate additional guidance on suitable barrier systems and features for motorcyclists including photographs/illustrations. Provide guidance on where barriers are most likely to be struck and where to start and end under-rail treatments on a curve.

7.2 Austroads Guide to Road Safety, Guide Review

Table 7.2: Austroads Guide to Road Safety – comments and proposed actions

Austroads Guide to Road Safety			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
Part 6: Road Safety Audit			
8.5 Designing for motorcyclists	107	This section discusses road safety issues specific to motorcyclists. However, the document does not provide enough guidance to conduct a comprehensive road safety audit targeting a motorcycle route. Further discussion is required outlining the different needs of motorcyclists and the casual factors and safety issues identified in this report.	Expand this section to include discussion of additional safety issues that have been identified as part of this project.
Checklists	121	There are currently limited items listed in the road safety audit checklists to specifically examine motorcyclist road safety issues when conducting a road safety audit. Inclusion of the additional safety issues that have been identified as part of this current research would benefit the road safety audit process.	Provide additional motorcycle guidance in the road safety audit checklists.
Part 9: Roadside Hazard Management			
2.0 Keeping vehicles on the road	2	Keeping motorcyclists on the road is crucial. Providing a well delineated, hazard free, consistent road surface with predictable road alignment can greatly reduce the risk of motorcycle crashes occurring. Providing a sufficient sealed shoulder to provide a recovery area for errant motorcyclists can prevent run-off road crashes which are potentially fatal to motorcyclists.	Highlight the importance of various road features that play an important role in keeping motorcyclists on the road.
3.2 Types of hazards and their treatments	10	This section discusses various roadside hazards and their treatment. There are a number of specific roadside hazards that are dangerous to motorcyclists e.g. signs and light posts and barrier kerb, signs in the lean zone, service pits, drainage pits. There are options available to reduce the risk to motorcyclists that could be included in this section.	Include discussion of roadside hazards specifically relevant to motorcyclists and their respective treatments.
3.3 Safety barriers	17	This section discusses the implications and the danger of safety barriers to motorcyclists. There is a section on 'Barriers and Motorcyclists' which outlines the hazards and motorcycle-friendly options available to minimise the severity of a crash if a motorcyclist strikes a barrier. There are additional treatments that could be included in this section such as capping of posts, end terminal treatments and underrun protection.	Update this section to include all available treatments to reduce the severity of motorcycle crashes if safety barriers are to be installed or retrofitted.

7.3 Austroads Guide to Pavement Technology, Guide Review

Table 7.3: Austroads Guide to Pavement Technology – comments and proposed actions

Austroads Guide to Pavement Technology			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
Part 3: Pavement Surfacing			
All sections	All	There is no discussion regarding how the selection of a pavement surface impacts on various road users, in particular motorcyclists. The pavement surface texture, skid resistance and, how the surface drains water are very important for motorcyclists. Any sudden change in surface texture or varying skid resistance, wind spray and aquaplaning may not impact greatly on other motorised vehicles, however they can have serious consequences for motorcyclists.	Provide guidance regarding the most suitable road surface types that are desirable for motorcyclists. Discuss the impacts of the various types of pavement surfaces on motorcyclists including texture, skid resistance and aquaplaning.
1.3 Overview	3	Table 1.1 outlines the needs of principal stakeholder groups in surfacing selection. There is no mention of motorcyclists needs in this table.	Include key needs of motorcyclists when selecting a road surface type in Table 1.1.
3.3.3 Skid resistance	17	This section defines skid resistance and includes how both microtexture and macrotexture can influence skid resistance. There is no discussion regarding the importance of skid resistance for individual road user groups. Skid resistance is particularly important for motorcyclists on the approaches to and on curves, at intersections, or where braking and manoeuvring is undertaken.	Provide guidance regarding the importance of skid resistance to motorcyclists. This should include discussion of the provision of adequate and consistent surface texture particularly at high risk locations such as curves and intersection approaches and turning lanes.
3.3.4 Texture	17	This section defines surface texture and includes discussion regarding how microtexture and macrotexture can influence skid resistance. There is no discussion regarding the importance of surface texture for individual road user groups. Surface texture is crucial to motorcyclists compared to other road users as a motorcycle relies on adequate and constant surface texture to remain upright during braking, turning, cornering and whilst redirecting a riding path or taking evasive action.	Provide guidance regarding the importance of surface texture to motorcyclists. This should include discussion of the provision of adequate and consistent surface texture with particular attention at high risk locations such as curves, intersection approaches and turning lanes. Importance is also to be placed on the long term performance of the wearing surface e.g. polishing of aggregates, bleeding and flushing, stripping and ravelling, build-up of material etc. which reduces the texture depth available resulting in poor skid resistance especially when there is a wet road surface. Provide guidance to prevent seal changes being located where turning, braking or evasive manoeuvres are undertaken by motorcyclists such as on approaches to curves, on curves, or at intersections where braking and turning is required by motorcyclists.

Austroads Guide to Pavement Technology			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
3.3.8 Water spray	21	This section discusses water spray and how it results from surface texture and poor surface drainage. It is mentioned how 'minimising water spray is particularly important on heavily trafficked, high-speed, multi-lane roads such as freeways, highways and heavily trafficked urban roads'. However, it also important to motorcyclists as tyre spray in the air and on a helmet visor can restrict vision, can result in a change of riding path or evasive action, can reduce friction between the surface and tyres, can affect motorcycle stability when braking and cornering and cause aquaplaning.	Provide discussion on how water spray affects motorcyclists.
3.3.9 Appearance	22	Section 3.3.9 discusses the different surface types and appearances that are available such as coloured asphalt, exposed aggregate finish, stencilled or stamped concrete finish, and concrete paved surfaces. There is no mention of the potential hazard of these to motorcyclists both in relation to a change in surface texture as well as where these are placed e.g. in braking areas, and intersections etc.	Provide guidance on the types and nature of the various pavement surface finishes in relation to motorcyclists. This would include where they are appropriate for use and where they should be avoided i.e. in braking areas, turning areas at intersection and how they impact on motorcyclists.
Part 7: Pavement Maintenance			
1.4 Intervention levels and network standards	3	This section provides an overview of maintenance intervention levels and how they are established. The reader is referred to Austroads *Guide to Asset Management – Part 1: Introduction to Asset Management* (Austroads 2009a) and Austroads (2009b), *Process for setting intervention criteria and allocating budgets: process description and application*, for routine maintenance standards. Specific intervention levels need to be established to trigger maintenance activities specific to motorcyclists as their needs are different to other road users.	Provide guidance on how to cater for the different needs of motorcyclists when establishing maintenance intervention levels. These should be managed by different response times, intervention levels and periodic treatments such as signage and temporary pavement marking on rural roads with a high percentage of motorcycles and on all urban roads.

Austroads Guide to Pavement Technology			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
2.2 Surface drainage	6	These sections define various pavement characteristics/defects, discuss maintenance methods/practices to repair defects, and discuss other road maintenance activities. Pavement defects or hazards can have a greater impact on motorcyclists compared to other road users as motorcyclists are far more vulnerable with severe consequences if a crash occurs. Good maintenance practices play an important role in reducing the likelihood of motorcycle crashes. These sections do not provide guidance on how these road attributes/defects affect motorcyclists, and what is needed to provide a consistent, uniform road surface free of hazards for motorcyclists.	Discuss how critical pavement attributes are to motorcyclists and provide guidance on how each of the pavement attributes and their condition impact on motorcyclist. Guidance on the priority given to each element during asset management programing, and the associated intervention levels for maintenance activities should be included.
2.3. Subsurface drainage	10		
3.2 Potholes	15		
3.3 Edge repairs	17		
3.4 Surface treatments	18		
3.5 Shape correction	20		
3.6 Pavement cleaning	22		
3.7 Preventative periodic (specific) maintenance and rehabilitation	22		
5.0 Maintenance of shoulders	26		
6.2 Incident and emergency management	27		
6.3 Snow clearing	29		
6.4 Utility crossings and other road openings	30		
6.5 Railway crossings	30		

7.4 Austroads Guide to Traffic Management, Guide Review

Table 7.4: Austroads Guide to Traffic Management – comments and proposed actions

Austroads Guide to Traffic Management			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
Part 3: Traffic Studies and Analysis			
2.5 Traffic surveys	18	This section outlines various types of traffic surveys that may be of use to practitioners. However, there is no guidance on how to conduct a survey specific to motorcyclists.	Provide an additional section which provides guidance on how to survey motorcycles as a unique road user group. The road type, geometry, motorcycle crashes, motorcycle AADT and pavement condition should be considered.
Part 4: Network Management			
2.2 User modes and needs of users of transport networks	6	Table 2.1 provides information regarding modes of transport and user needs. Motorcyclists are included as a separate user group in the table, however it states the needs of motorcyclists are the 'same as cars'. This is not the case. This information could be expanded upon to include additional needs of motorcyclists e.g. delineation, consistent pavement surfaces, right turn provision etc.	Update Table 2.1 to discuss the specific needs of motorcyclists.
Part 5: Road Management			
3.4 Allocation of road space between road user groups	29	Table 3.2 'Road space requirements for different road user groups' includes a section in the table on motorcyclists. This section could be expanded to include requirements for motorcyclists at intersections as well as other general requirements based on the research findings.	Provide additional guidance in Table 3.2 on providing for motorcyclists including requirements at intersections and other general requirements based on research findings.
Part 6: Intersections, Interchanges and Crossings			
2.2.2 Selection process	8	This section has a heading 'road user volumes and movements'. It discusses determining the volumes of road users other than cars and mentions public transport, heavy vehicles, pedestrians and cyclists but motorcyclists are not mentioned.	Include motorcyclists in the examples of other road users in the section 'road user volumes and movements'.
2.2.4 Intersection type selection – key traffic management considerations	13	Table 2.4 outlines key traffic management considerations in selection of intersection type. It provides key areas for consideration for each type of intersection e.g. unsignalised, signalised, roundabouts, interchanges etc. There is no mention of the needs of motorcyclists at the different types of intersections.	Include the needs of motorcyclists at the various types of intersections in Table 2.4 e.g. providing high surface friction on approaches and on roundabouts, turning provision at intersections due to low visibility of motorcyclists, right turn phasing.
3.0 Unsignalised intersections	20	Table 3.3 outlines issues at intersections for different road user categories. The table has a section allocated to motorcyclists where a number of issues are discussed and appropriate remedial actions are provided to address the issues. The list of issues should be expanded to incorporate the research findings.	Expand the section on motorcyclists in Table 3.3 to include additional issues at intersections identified in this research.

Austroads Guide to Traffic Management			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
4.0 Roundabouts	36	There are individual sections dedicated to providing for pedestrians and cyclists at roundabouts. There is no mention of the needs of motorcyclists. The needs of motorcyclists needs to be addressed in this section to provide guidance on how to adequately cater for motorcyclists at roundabouts.	Incorporate a section to discuss the needs of motorcyclists at roundabouts including good delineation, the clear identification of the roundabout from the approach, including the centre island, kerbing on the approach and the radius of the circulating carriageway, provision of a high friction surface on the approach and throughout the roundabout, minimal hazards within the lean zone.
5.3 Road space allocation	57	Table 5.2 'Road user requirements for arterial road signalised approaches' and Table 5.3 'Road user requirements for local road signalised approaches' discuss user requirements for various road user groups. There is no mention of the needs of motorcyclists in either of these tables.	Include motorcyclists as a road user group in Table 5.2 and Table 5.3 and provide guidance on providing for motorcyclists at signalised intersections.
5.4 Lane management	63	Table 5.4 discusses lane management at signalised intersections. It provides guidance on lane requirements for various road user groups, however, motorcyclists have not been included.	Include motorcyclists as a road user group in Table 5.4 and provide guidance on the lane requirements for motorcyclists at signalised intersections e.g. turning lane requirements and signal phasing (dedicated right turn).
5.5 Signal phasing	66	Motorcyclists can be difficult to see whether they are undertaking a right turn manoeuvre or whether a vehicle is undertaking a right turn manoeuvre and a motorcyclist is travelling through the intersection. A filtered right turn does not reduce the likelihood of a crash occurring. A dedicated right turn phase would reduce the potential conflict of vehicles/motorcyclists and thus reduce the likelihood of right turn crashes occurring. No guidance regarding dedicated right turn phasing for motorcyclists is provided in the guide.	Provide guidance on the use of dedicated right turn phasing for motorcyclists.
5.8 Traffic detection	79	Section 5.8 discusses the use of detector loops at signalised intersections. Motorcyclists can often not be detected by the loops due to calibration issues or the positioning of the loop relative to the hold line. The difficulty of detecting motorcycles is acknowledged in the Guide, however, this is still an issue that needs to be addressed particularly if detector loops are being used on motorcycle routes.	Provide guidance on the calibration of the detector loops so that they are able to detect motorcycles, and the most appropriate location of the detector loop with respect to the hold line to ensure all vehicle types can be detected.

7.5 Austroads Guide to Asset Management, Guide Review

Table 7.5: Austroads Guide to Asset Management – comments and proposed actions

Austroads Guide to Asset Management			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
Part 1: Introduction to Asset Management			
Commentary 4	31	Section C4.1 does not mention the fact that road operating conditions are different for different road users e.g. motorcycle requirements for road roughness and condition may be different to other vehicles.	Make a provision/acknowledge that road operating condition standards vary for different user groups.
Part 3: Asset Strategies			
All	All	This Guide discusses investment strategy – asset use, LOS consideration, treatment prioritisation, new trigger values (motorcycle AADT, geometry, surface type, and surface condition). There is no mention on how to identify and include the needs of motorcyclists in the strategies.	At network asset strategy level, investment strategy should be driven by road user/community preference such as: prioritising maintenance treatment on routes which are known for high motorcycle volumes or specific routes for tourism improvement projects triggered by road safety audit specifically for motorcycles development of business cases for funding motorcycle specific improvements. At asset management operation level: medium to long term approach when modelling to include treatment and triggers concerning motorcycles condition attributes to be considered; edge drop, rut depth extent, combination of geometric and surface defects. treatments to be considered; shoulder sealing, improvement of skid resistance around corners tying routine maintenance response time to activities which are potential contributors to motorcycle-related accident such as: pothole patching, edge drop, line marking.
Part 4: Program Development and Implementation			
3 Identification of asset requirements	14	This section identifies standards of performance, condition and capacity and the consequential funding requirements. LOS framework is used to assess the asset requirements, this is inclusive of the roads strategic importance (function and usage), however does not clearly identify the LOS for all road users such as motorcyclists.	LOS framework should also consider a separate factor in its definition (apart from road hierarchy, environment and social impacts) – special road user groups that require different LOS.

Austroads Guide to Asset Management			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
3.1.2 Road hierarchy	15	LOS target road asset conditions, and road configuration parameters defined for all road users do not specifically mention motorcycles as a road user, nor the unique LOS they require.	Research and develop LOS parameters and targets that are relevant for motorcycles.
3.1.3 Community consultation	16	Community consultation to define asset requirements does not mention motorcyclists.	Mention the various road user groups, including representatives from all user groups including motorcyclists, cyclists, etc.
3.2 Setting performance targets/interventio n criteria	16	There is no mention of performance targets or intervention criteria specific to road user group needs.	Include text to indicate that different road user groups will have different requirements and resulting performance targets and intervention levels should be set according to the traffic mix (percentage of motorcycles).
3.2.1 Maintenance intervention criteria	17	Intervention levels and response times are not specific to the needs of various road user groups.	Intervention levels and response times should be set according to the traffic mix particularly for routine maintenance intervention levels and response times. Research should be undertaken to provide guidance on the intervention levels and response times suitable for motorcycles.
3.2.2 Approaches to setting maintenance intervention criteria	18	The risk assessment and economic analysis does not specifically outline the variants in risk, crash likelihood, and the effects road condition has on various road groups.	Guidance should be provided on the unique crash risks for each road user group, economic analysis should consider the higher crash risk of motorcycles and the whole-of-life cycle costs dependent on the road condition and number of motorcycles on a road. Introduce consideration of risk specific to motorcycles as part of multi-criteria analysis.
4.3 Maintenance treatments and strategies	24	Network level approach uses computer based automatic processes. It is not clear if motorcyclists are identified separate to other road user groups.	Ensure that computer based algorithms prioritise based on high proportional fatalities in all user groups, not just high total fatality road sections. This will ensure that other user groups apart from cars/trucks are not marginalised, and high risk road sections are included in network level approach to be remedied.
4.5.1 Whole of life cycle cost analysis (WOLCC)	28	WOLCC is very rigid and standardised (e.g. Using total traffic volumes and considering monetary values only), to determine what is prioritised and up for maintenance.	Apply WOLCC for different user groups, and evaluate measures to reduce total cost for each group. There are likely low-hanging benefits that are currently being overlooked and undervalued through the WOLCC being applied system-wide.
Part 5: Pavement performance			
2 Measurement of pavement performance	7	Pavement performance indices considers pavement condition attributes, however these are not specific to different to road users.	Composite indices assumes pavement performance on same scale and impact on all road users. Acknowledge that different user groups are more sensitive to pavement condition (e.g. motorcyclists), and require a separate index/different assessment criteria.

Austroads Guide to Asset Management			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
Part 5B: Roughness			
1.2 Overview of roughness	1	Discusses how roughness affects vehicle dynamics and ride quality for passenger vehicles however does not mention the vehicle dynamic and safety implications that roughness has on motorcycles.	Include information and guidance on how roughness affects motorcycle stability and increases motorcycle crash likelihood. Further research is required to give guidance on the relationship between motorcycle crash risk and various levels of roughness.
Part 5C: Rutting			
1.2 Overview of rutting	1	Does not discuss how rutting affects vehicle dynamics and ride quality for road users, particularly does not mention the vehicle dynamic and safety implications that roughness has on motorcycles.	Include information and guidance on how rutting affects motorcycle stability and increases motorcycle crash likelihood. Further research is required to give guidance on the relationship between motorcycle crash risk and various levels of roughness.
6.3 Network screening	18	It is not indicated that network screening of rutting condition data and consequent work prioritisation, and performance indicators are inclusive of the requirements to maintain safety for motorcyclists.	Prioritise rutting on curves, and at intersections (namely in braking and turning zones) in network screening phase to warrant further investigation.
Part 5F: Skid Resistance			
1.2 Overview of Skid resistance	1	Does not discuss how surface texture affects vehicle dynamics and ride quality for road users, particularly does not mention the vehicle dynamic and safety implications that roughness has on motorcycles.	Include information and guidance on how surface texture affects motorcycle stability and increases motorcycle crash likelihood. Further research is required to give guidance on the relationship between motorcycle crash risk and various levels of rutting.
6.5 Investigatory levels	29	The relationship between skid resistance and crash risk is discussed, particularly where 'high stress' manoeuvres are carried out. There is no mention of the importance of skid resistance for motorcycles, particularly at intersections for braking/accelerating/turning or on curves for maintaining co-efficient of side friction.	Provide guidance on the reliance a motorcycle has on skid resistance at intersections and on curves.
Part 5G: Texture			
1.2 Overview of skid resistance	1	Does not discuss how skid resistance affects vehicle dynamics and ride quality for road users, particularly does not mention the vehicle dynamic and safety implications that skid resistance has on motorcycles.	Include information and guidance on how skid resistance affects motorcycle stability and increases motorcycle crash likelihood. Further research is required to give guidance on the relationship between motorcycle crash risk and various levels of skid resistance.
Part 7: Road-related Asset Performance			
4.2.7 Signs and Delineation	14	This section of the Guide discusses the importance of maintaining roadside vegetation with regards to vegetation, wildlife management, and maintaining an aesthetically pleasing roadside. There is no mention of the implications roadside vegetation has on drainage, surface debris or sightlines, particularly the follow on effects that effect motorcyclists.	The guidance should include also identify that roadside vegetation should also consider the amount of debris dropped onto the road surface, drainage blockage and redirection of water and the restriction of sightlines. These should all be managed effectively on routes used by motorcyclists, particularly on low order roads.

Austroads Guide to Asset Management			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
4.2.7 Signs and Delineation	17	This section of the Guide discusses the importance of maintaining the condition and quality of signage and delineation during the day and night. It highlights the requirements to maintain signage and linemarking for legal purposes and proactively replacing signs before they are ineffective. There is no mention of replacing signs and lines to maintain a level of safety, particularly for motorcyclists who rely on good signage and linemarking.	The guidance should indicate that poor condition of signage and linemarking increases the likelihood of a crash occurring, particularly for motorcyclists on low order roads and on high order roads where kerbing is used.

7.6 Austroads Guide to Road Transport Planning, Guide Review

Table 7.6: Austroads Guide to Road Transport Planning – comments and proposed actions

Austroads Guide to Road Transport Planning			
Section	**Page no.**	**Comments**	**Proposed actions for consideration**
All sections	All	This document does not mention motorcyclists with regard to transport planning.	Provide guidance to enable the needs of motorcyclists to be addressed when planning a transport network where a high proportion of motorcyclists are expected or on links forming part of a designated motorcycle route.

8. Safety Assessment of Mitigation Measures

8.1 Assessment Process

8.1.1 AusRAP and Mitigation Measures

The AusRAP risk assessment process was used to assess the motorcycle crash risk reduction potential (in terms of fatal and serious injuries (FSI) saved) of the main infrastructure related mitigation measures. The assessment investigated the impacts of individual countermeasures and combinations of measures. The measures considered include improvements to:

- delineation and curve quality
- road condition
- intersections (right turn lane, intersection quality and channelisation)
- sight distances
- pavement width – shoulder and lane widening especially on curves
- roadside hazard management.

AusRAP star rating is a methodology, based on the iRAP protocol with an associated web-based visualisation and analysis tool, ViDA, which is used to assess the safety potential of roads, provides star ratings by road user type (vehicle occupants, motorcyclists, bicyclists and pedestrians). The outputs can be used to develop road safety investment plans based on cost-effective countermeasures.

The star ratings are derived from a Star Rating Score (SRS), which in turn is determined from road safety inspection data and known relationships between road attributes and crash rates. The SRS concept provides an objective measure of the likelihood of a crash occurring and its severity (i.e. it provides a measure of the inherent safety of a road). The aim of the SRS is to provide a star rating of the road network in a similar manner to the current five-star rating scales for new car safety. A 5 Star road provides road users with the safest form of road infrastructure design and roadside environment and a 1 Star rating represents a road with relatively poor road design features.

8.1.2 Study Network

Magill – Lobethal Road in South Australia was selected as the case study network (Figure 8.1). This road was the subject of a recent study into motorcycle crashes by ARRB and the South Australian Department of Planning, Transport and Infrastructure. This is a low volume, undivided two-lane, two-way road with a total length of 35 km. Traffic composition is as follows:

- AADT – 3100
- Motorcycle flow – 110.

Figure 8.1: Extent of the study network, Magill – Lobethal Road, South Australia

Source: Provided by ARRB Group.

8.1.3 Crash Data

Fatal and serious injury crash data (Table 8.1) over a five-year period (2006–10) was used to calibrate the AusRAP fatality estimation model. The fatality calibration ensures a true reflection of the typical crash types along a road network is distributed across the network. A summary of the crash data is provided below. On average there were 2.4 fatal and serious injuries for motorcyclists per year on this road during the study period.

Table 8.1: Crash statistics (2006–10) on Magill – Lobethal Road

Year	All crashes			Motorcyclists		
	Fatalities	Serious injuries	FSI	Fatalities	Serious injuries	FSI
2006	0	4	4	0	1	1
2007	1	6	7	0	2	2
2008	1	4	5	1	2	3
2009	0	3	3	0	0	0
2010	2	6	8	1	3	4
Total	**4**	**23**	**27**	**2**	**8**	**10**
Annual average	**0.8**	**4.6**	**5.4**	**0.4**	**1.6**	**2**

8.1.4 Road Infrastructure Data

The road infrastructure data was collected by viewing the video image of the road and the recording of several road attributes using pre-designed rating forms as shown in Figure 8.2. The video data was collected by a specialist vehicle, equipped with four cameras (forward, right, left and rear). An example of the video data is shown in Figure 8.3.

The road data was recorded at 100 m intervals. The recorded data was supplemented with AADT and GPS data. The resulting composite data was then uploaded for processing, analysis and calculations of SRS, star ratings, fatality estimates and investment level.

Figure 8.2: Coding form in Hawkeye for determining attributes along the road

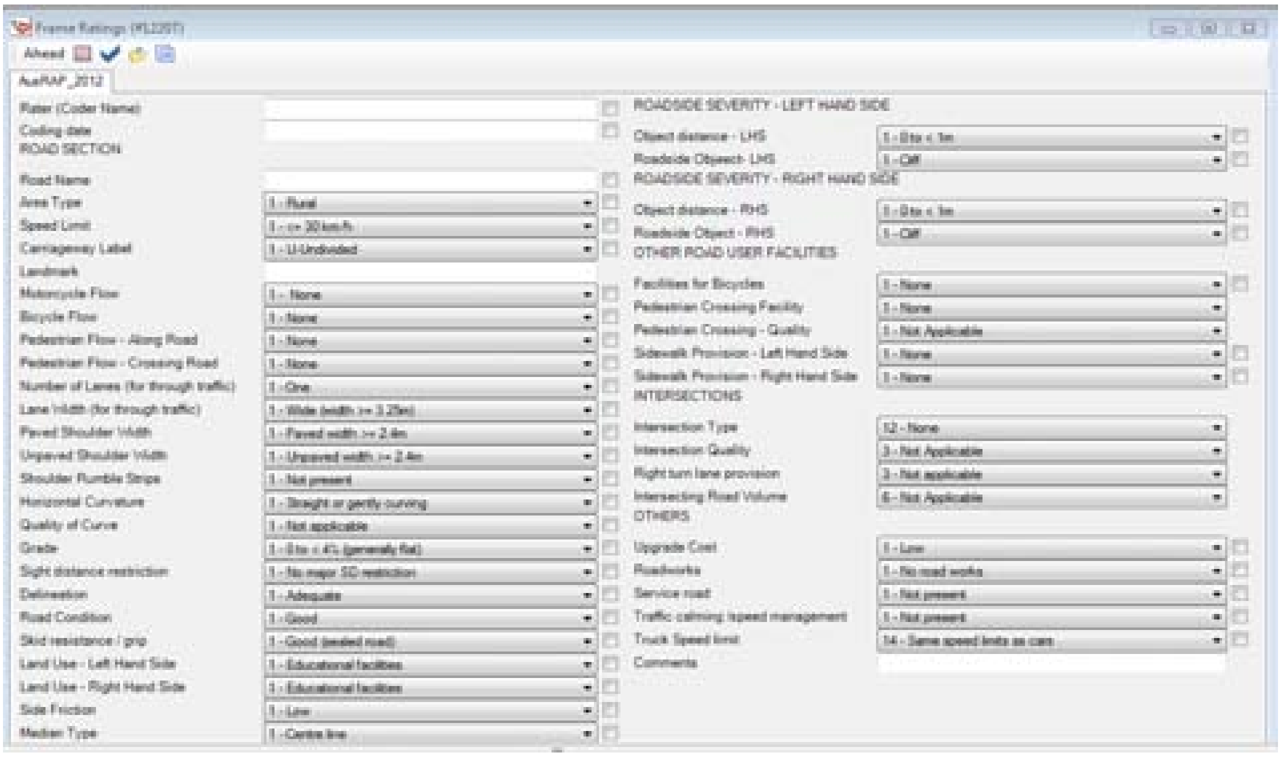


Figure 8.3: Hawkeye video data of surveyed roads

8.2 Results

8.2.1 Star Ratings

The star ratings of the assessed road is shown in Figure 8.4. The existing road condition shows a predominantly 1 Star road (87%) for motorcyclists, with only 8% as 3 Star (Table 8.2). There are no 4 or 5 Star sections.

Figure 8.4: Motorcycle star rating for Magill – Lobethal Road

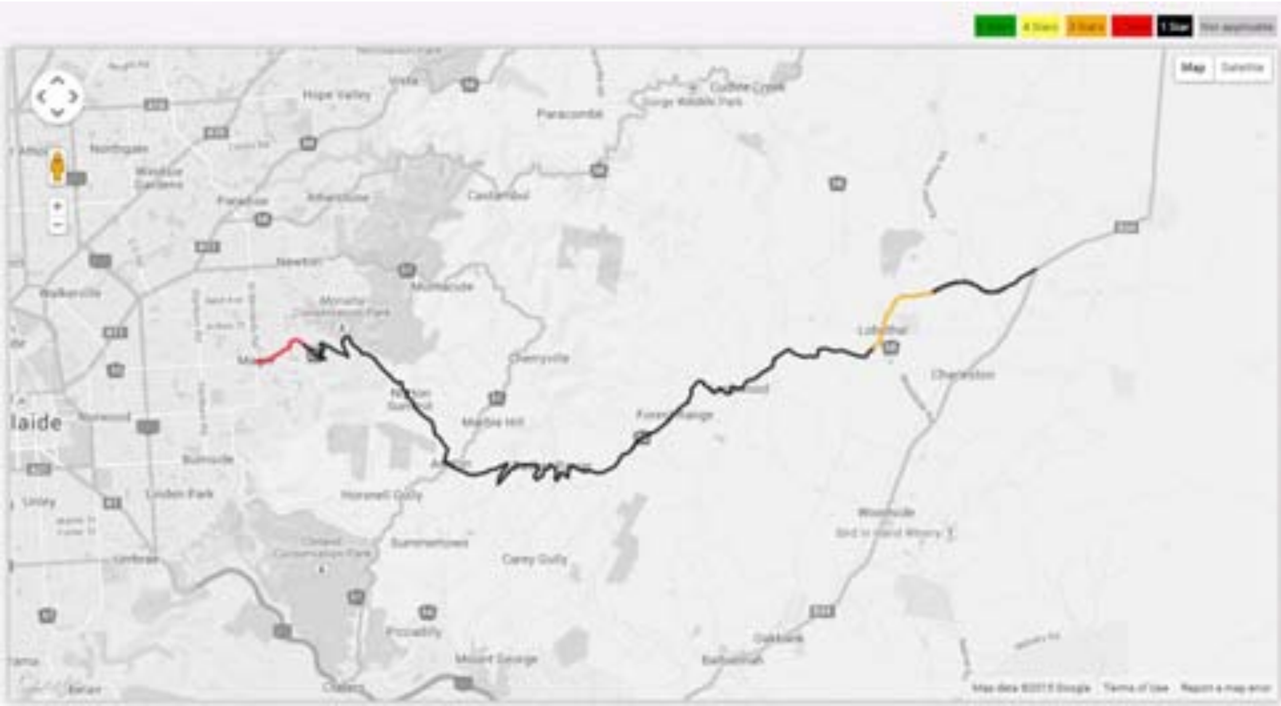


Table 8.2: Distribution of star ratings for Magill – Lobethal Road

Star ratings	1 Star	2 Stars	3 Stars	4 Stars	5 Stars	Total
Length (km)	30.5	1.8	2.7	0	0	35
Proportion (%)	87	5	8	0	0	100

8.2.2 Detailed Star Rating Scores

The distributions of the star rating scores for the 100 m coded sections and smoothed sections (over 3 km length) are shown in Figure 8.5 and Figure 8.6, respectively.

Figure 8.5: Risk worm – 100 m sections, Magill – Lobethal Road

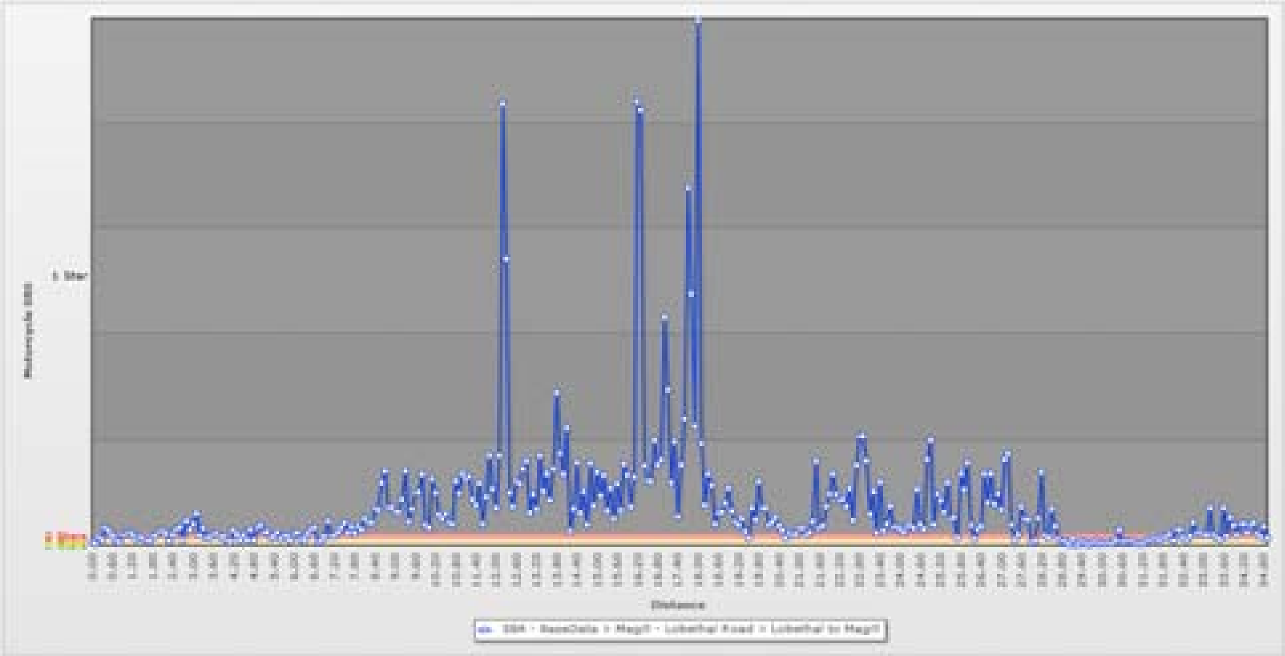
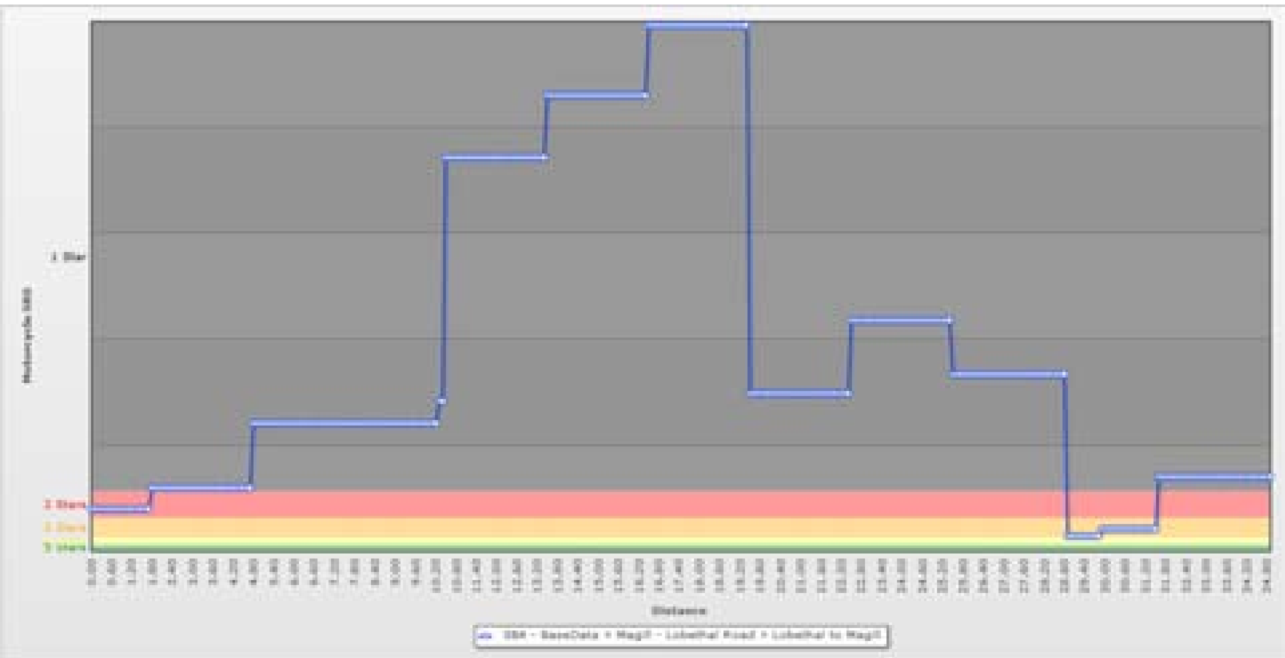


Figure 8.6: Risk worm – Smoothed sections (3 km length), Magill – Lobethal Road



8.2.3 Key Safety Features of the Road

The software allows identification of the key road safety features that influence the star rating a road section. These include:

- carriageway type: the entire road section is undivided with the potential for head-on collisions
- speed limit: 36% of the network has a signed speed limit of 60 km/h or less; 64% has speed limit of 80 km/h and above
- roadside severity: about 42% of the network has unforgiving roadside conditions (within 5 m from the road) due to the presence of trees, non-frangible poles, aggressive vertical faces, rollover upward slopes, steep downward slopes, etc.
- lane width: 13% has wide lanes (> = 3.25 m), 72% has medium lanes (2.75 m to 3.25 m, and 15% has narrow lanes (< 2.75 m)
- horizontal curvature: 33% of the network has good curvature (67% has sharp to very sharp curvature)
- skid resistance ('grip'): 70% of the network has adequate skid resistance (visual assessment); 30% is classified as medium to poor skid resistance (visual assessment)
- road condition: 58% of the network has good road condition and 42% is classified as having poor road condition
- delineation: 57% has good delineation and 43% has poor delineation
- paved shoulder: on the passenger side 86% of the network has no or very narrow shoulder width less than 1 m while on the driver side, 91% has no or very narrow shoulder width less than 1 m
- intersection frequency: high intersection density, one intersection for every 0.64 km.

Through the identification of the road features that most adversely affected motorcycle safety, these road features were then able to be targeted for treatment.

8.2.4 Impact of Mitigation Measures and Investment Plan

The AusRAP model allows for the develoment of a Safer Road Investment Plan (SRIP). The SRIP recommends cost-effective countermeasures for improved safety outcomes on the assessed road.

Considering all available countermeasures and assuming a cut-off BCR > = 1.0 (i.e. all countermeasures which have a positive effect), it is estimated that the recommended investment plan for the study road would prevent 26 FSIs over the next 20 years with an economic benefit of $28 million in terms of crash costs saved, with program BCR of 2.0 (Figure 8.7 and Table 8.3). The top five countermeasures in terms of FSIs saved are roadside barriers – passenger side, roadside barriers – driver side, improvements to road condition (especially with respect to skid resistance) and general and curve delineation. It should be noted that, while safety barriers increase the likelihood of crashes and reduce crash severity, and hence improve overall safety for motorcyclists, the roadside barrier installed should be motorcycle-friendly.

Figure 8.7: Recommended cost-effective countermeasures

Total FSIs Saved	Total PV of Safety Benefits	Estimated Cost	Cost per FSI saved	Program BCR
26	28,010,290	14,362,748	548,783	2

Countermeasure	Length / Sites	FSIs saved	PV of safety benefit	Estimated Cost	Cost per FSI saved	Program BCR
Roadside barriers - passenger side	10.10 km	6	6,122,277	3,173,338	554,733	2
Roadside barriers - driver side	13.20 km	6	6,150,952	4,133,382	719,190	1
Skid Resistance (paved road)	8.80 km	6	6,270,276	2,923,207	498,946	2
Improve curve delineation	7.10 km	3	3,639,022	1,661,054	488,517	2
Improve Delineation	7.40 km	1	1,159,994	503,747	464,770	2
Clear roadside hazards - passenger side	6.00 km	1	953,105	260,730	292,773	4
Clear roadside hazards - driver side	5.70 km	1	994,374	234,764	274,201	4
Shoulder rumble strips	2.80 km	1	780,940	630,202	863,659	1
Sight distance (obstruction removal)	1.80 km	1	1,070,968	96,138	96,073	11
Lane widening (up to 0.5m)	0.30 km	0	195,034	153,581	842,764	1
Delineation and signing (intersection)	1 sites	0	139,920	64,682	494,746	2
Sideslope improvement - passenger side	0.10 km	0	25,795	21,950	910,721	1
Shoulder sealing passenger side (>1m)	0.40 km	0	243,027	120,244	529,530	2
Shoulder sealing driver side (<1m)	1.20 km	0	114,012	129,961	1,219,953	1
Shoulder sealing driver side (>1m)	0.90 km	0	150,595	235,767	1,675,529	1
		26	28,010,290	14,362,748	548,783	2

Table 8.3: Economic analysis – motorcycle crashes only

Fatal and serious injuries (FSI)	Fatalities (per year)	Fatal and serious injuries (per year)	Fatal and serious injuries (20 years)
Before mitigation measures	0.40	2.4	48.0
After mitigation measures	0.28	1.1	22.0
FSI prevented	0.12	1.30	26.0
PV of safety benefit (20 years)	$28.01 million		
Investment cost (20 years)	$14.36 million		
FSI reduction	54.17%		
Program BCR	1.95		

It is also estimated that the implementation of recommended cost-effective countermeasures identified in the SRIP would result in a 77% reduction in the length of 1 Star rated sections (for motorcyclists) from 87% to 10% (Table 8.4), i.e. the road would go from a mostly 1 Star rating to a mostly 2 Star rating (Figure 8.8).

Table 8.4: Distribution of star ratings for motorcyclists – after countermeasure treatments

Star ratings	1 Star	2 Stars	3 Stars	4 Stars	5 Stars	Total
Length (km)	3.6	26.9	4.5	0	0	**35**
Per cent	10%	77%	13%	0%	0%	**100%**
Change after treatment	– 77%	+ 72%	+5%	0%	0%	**0**

Figure 8.8: Motorcycle star rating for Magill – Lobethal Road (assuming all cost-effective treatments are implemented)

8.2.5 Impact of Individual Mitigation Measures

The impact of the individual measures on motorcycle safety are provided in Figure 8.9 to Figure 8.14, this tables indicate the results when only those treatments are activated. The study indicates that:

- Roadside hazard management (barrier treatment and hazard removal) would save 21 FSIs over 20 years with a program BCR of 3.
- Road surface rehabilitation (for skid resistance and road condition improvement) over 8.8 km would save nine FSIs over 20 years with a program BCR of 3.
- Improved delineation (including curve delineation) would save seven FSIs over 20 years with a program BCR of 3.
- Sight distance improvement would save one FSI over 20 years with a high program BCR of 12.
- Lane and shoulder widening were found to be cost-effective over only a very short section of the network with minimal impact on FSI saved. This is site specific and due to the road being on mountainous terrain and cut or fill being required.
- Intersection improvements were found to be cost-ineffective in terms of an improved safety outcome for motorcyclists.

The treatments with the highest BCRs are sight distance, roadside hazard management, skid resistance and delineation improvement especially on curves.

Figure 8.9: Roadside hazard management BCR

Countermeasure	Length / Sites	FSIs saved	PV of safety benefit	Estimated Cost	Cost per FSI saved	Program BCR
Roadside barriers - passenger side	10.10 km	10	10,765,502	3,173,338	315,471	3
Roadside barriers - driver side	13.20 km	9	9,659,037	4,133,382	457,986	2
Clear roadside hazards - passenger side	6.00 km	1	1,071,495	260,730	260,425	4
Clear roadside hazards - driver side	5.70 km	1	1,054,552	254,764	258,554	4
		21	22,550,667	7,822,215	371,237	3

Figure 8.10: Skid resistance and road condition (road surface rehabilitation) BCR

Countermeasure	Length / Sites	FSIs saved	PV of safety benefit	Estimated Cost	Cost per FSI saved	Program BCR
Skid Resistance (paved road)	8.80 km	9	9,283,844	2,923,207	336,906	3
		9	9,283,844	2,923,207	336,906	3

Figure 8.11: Delineation and curve delineation BCR

Countermeasure	Length / Sites	FSIs saved	PV of safety benefit	Estimated Cost	Cost per FSI saved	Program BCR
Improve curve delineation	7.10 km	5	5,750,777	1,661,054	309,127	3
Improve Delineation	7.50 km	1	1,447,285	510,583	377,566	3
		7	7,198,062	2,171,636	322,808	3

Figure 8.12: Sight distance BCR

Countermeasure	Length / Sites	FSIs saved	PV of safety benefit	Estimated Cost	Cost per FSI saved	Program BCR
Sight distance (obstruction removal)	1.80 km	1	1,151,428	96,138	89,359	12
		1	1,151,428	96,138	89,359	12

Figure 8.13: Shoulder widening BCR

Countermeasure	Length / Sites	FSIs saved	PV of safety benefit	Estimated Cost	Cost per FSI saved	Program BCR
Shoulder sealing passenger side (>1m)	0.40 km	0	471,923	120,244	272,893	4
Shoulder sealing driver side (>1m)	1.20 km	0	175,802	129,961	780,719	1
Shoulder sealing driver side (>1m)	0.90 km	0	291,857	235,767	865,148	1
		1	939,483	485,972	553,609	2

Figure 8.14: Lane widening BCR

Countermeasure	Length / Sites	FSIs saved	PV of safety benefit	Estimated Cost	Cost per FSI saved	Program BCR
Lane widening (up to 0.5m)	0.30 km	0	346,795	153,581	473,963	2
		0	346,795	153,581	473,963	2

8.3 Summary Findings

The existing road condition of the study road shows a predominantly a 1 Star road (87%) for motorcyclists. It can be improved to predominantly a 2 Star road by implementing recommended countermeasures.

The countermeasures proposed show how a budget can be used to achieve the best outcome in terms of fatalities and serious injuries saved and where that investment should be directed. On this road, the main cost-effective measures are roadside hazard management, surface rehabilitation (skid resistance, road surface improvements), delineation improvements (especially on curves), sight distance improvements (midblock), lane and shoulder widening and improvements to intersection quality (layout, sight lines, signage and delineation).

The analysis showed that by treating the road infrastructure elements that affected only crash likelihood, 18 FSI crashes could be prevented over 20 years with BCRs (calculated using Qld willingness-to-pay figures) for each treatment ranging between 2 and 12. The treatments included improvements to skid resistance and road condition, delineation and curve delineation/curve quality, sight distance, sealed shoulder widening and lane widening.

The analysis showed that by treating the road infrastructure elements that affected only crash severity, 12 FSI crashes could be prevented over 20 years with a BCR of 3. The treatments included providing motorcycle safety barriers and clearing roadside hazards. It should be recognised that the likelihood of clearing roadside hazards is low.

It should be noted that the road selected is on mountainous terrain with a narrow formation with steep embankment or cuttings either side of the road. Some mitigation measures showed a low BCR due to the cost of undertaking earthworks. These measures however would result in a higher BCR on roads with wider formations and hence, requiring less earthworks.

9. Conclusion and Recommendations

9.1 Conclusions

This report investigates the relationship between motorcycle crashes and road infrastructure. The road infrastructure influences both the likelihood of a motorcycle crash occurring and its resulting severity. This project incorporated:

- a literature review
- a crash analysis
- the identification of road infrastructure as a crash factor
- the identification of mitigation measures
- consultation with stakeholders
- a review of Austroads Guides for motorcycle related content
- conduct a safety and cost-benefit analysis of mitigation measures using an Australian case study.

Literature review

The literature review affirmed that road infrastructure contributes to both the likelihood and severity of motorcycle crashes, predominantly with regard to pavement condition and roadside hazards and safety barriers. It was apparent that, of the publications reviewed, the intent was to provide a practical guide (mainly based on experience), as opposed to providing technical guidance to justify engineering decisions. Typically, the literature did not systematically identify all of the elements of road infrastructure that influence motorcycle crash risk, or the risk factor for each element, or more significantly, the resulting risk when a number of elements are concurrent (combined).

Crash analysis

The crash analysis identified that the rate of motorcycle crashes at intersections, on a curve or a straight vary depending upon the travel period. A travel period is defined as commuting (weekdays) and recreational (weekends and public holidays). The majority of crashes occurred in the commuting period (64% average). A majority of crashes occurred on a straight or at an intersection. A higher proportion of crashes occurred on curves during the recreational period and on straights and at intersections during the commuting period. The proportion of crashes involving a motorcycle on a curve was higher than the proportion of crashes involving vehicles. This was particularly evident for multiple vehicle and motorcycle only, crashes during the recreational period. The majority (95% average) of motorcycle crashes at an intersection occurred at a T-junction (50% average), crossroad (33% average) and roundabouts (12%).

Road infrastructure as a motorcycle crash factor

It was identified that each road infrastructure element for a midblock section or an intersection has an influence on motorcycle crash risk (the likelihood of a motorcycle crash occurring and the severity of a crash if it occurs). Lane width, shoulder width (sealed), curve type and radius, horizontal and vertical sight distances, the condition of the road surface (i.e. deterioration, deformation), objects on the road surface (i.e. service covers, debris), surface texture, drainage of the road surface, signage, delineation and curve quality (i.e. curve warning signs, CAMs) were all identified as affecting the likelihood of a motorcycle crash occurring. Using the AusRAP model, the likelihood of a crash occurring increased as various road infrastructure elements were either at minimum standards, or more than one element was unfavourable for motorcycles. The research showed almost all roadside objects can be hazardous to motorcyclists. Roadside objects that have been designed to provide safety performance for passenger vehicles do not always provide a safety function to motorcyclists. If a roadside object is struck by a motorcyclist, the resulting crash severity is dependent on collision speed, impact angle, the surface area of the object and the impact absorption properties of the object.

Mitigation measures

The mitigation measures identified address the likelihood of a crash occurring and the severity of a crash if it did occur. The measures focus on knowledge transfer of the findings in this report and the collaboration of all road engineering disciplines such as; safety, design, asset management, highway maintenance and pavement technology.

A majority of the mitigation measures can be integrated into existing practice, and programming and carried out under existing funding, with this applying particularly to asset management and maintenance. Some mitigation measures could also be applied at the road design stage. For this to come into fruition an update of the Austroads Guides for design, safety, asset management, pavement technology, traffic management and transport planning would need to be actions, as per the recommendations in Section 7.

Use of proactive RAPs such as the ANRAM, AusRAP and iRAP is recommended in identifying motorcycle crash risk at locations or on routes/networks. A motorcycle specific road safety audit, as developed by ARRB Group can be undertaken to identify high risk locations for priority action and motorcycle specific treatment recommendations can be provided. Treatment recommendations consider an industry-recognised hierarchy of controls and focus on whether a treatment is reducing the likelihood or severity of a crash, providing alignment with the Safe System approach.

Motorcycle specific warning signage was recommended for use on rural roads to raise awareness of the dangers the road may present to motorcyclists and also alert other vehicle drivers to be aware of motorcycles on the route, particularly at intersections and on curves (especially with narrow lane widths).

Mitigation measures for prominent crash types

On midblock sections, it was found that the proportion of crashes involving a motorcycle on curves was higher than the proportion of crashes involving passenger vehicles on curves, and as a result, targeted mitigation measures have been provided. The most common crash types on curves identified in the crash analysis were head-on crashes and run-off curve crashes. The most effective mitigation measures to reduce crash risk on curves were found to be; improvements to the road surface (in particular re-surfacing) on curves, curve approaches and departures; improving and maintaining delineation and curve warning/quality signage. These activities should be a focus of asset management programming and maintenance activities. Lane widening and sealed shoulder widening on curves is also favoured. A wide centre line can further reduce the crash risk. These treatments are applicable on all road types, however higher order roads generally do not require the same level of intervention as lower volume roads.

At intersections it was found that the highest proportion of motorcycle crashes were vehicle adjacent approach (thru-right), opposite approach (thru-right) and adjacent approach (thru-thru). The most effective mitigation measures to reduce crash risk at intersections were to; provide sightlines at intersections to allow for SISD, separate all movements at signalised intersections with designated right turn lanes; and protecting turning motorcyclists (signalised and unsignalised) with channelised right and auxiliary left turn lanes.

Consideration should be given to providing a greater SISD to cater for potential longer stopping distances of motorcyclists and also providing sight lines for SISD to a vehicle on the side road as it approaches the intersection. In the likely event that SISD or ASD are not able to be provided due to buildings or infrastructure in an urban environment or require high cost earthworks in the rural environment, warning signage should be provided, in the event standard warning signage is ineffective, alternative treatments such as intersection ahead pavement markings or vehicle activated signs can be used.

Providing designated motorcycle lanes and head start areas at intersections is also favoured, to guarantee that motorcyclists are able to move to the front of the queue, so reducing the likelihood of motorcycles being directly or indirectly involved in rear-end crashes and sideswipe crashes whilst turning.

Stakeholder consultation

The early findings of the study were shared for feedback via a survey and then discussed in a workshop. Stakeholders from the Australian Motorcycle Council, state motorcycle advocacy groups, iRAP, practitioners from road design, road safety, finance, road operations, network programs, asset management and maintenance road engineering disciplines of state road agencies across Australia and NZ participated.

The survey results and workshop discussion concluded that the findings of the project were relevant to the current issues for both motorcyclists and road managers. It was unanimously concluded that identifying motorcyclists as a road user group and providing technical guidance to provide for them in a number of Austroads Guides (as outlined in the mitigation measures) would be required to raise awareness. It was also recognised that motorcycle crash risk can be managed through existing asset management programming, maintenance and road design practices.

Review of Austroads Guides

A review of the Austroads Guides for design, safety, pavement technology, traffic management, asset management and transport planning identified that there are some references to motorcyclists in the safety and design Guides, however the Guides for pavement technology, traffic management, asset management and transport planning do not cater for motorcyclists.

Within the design and safety Guides, comprehensive guidance on what the issues are and how they influence motorcycle crash risk is not provided. There is not enough information for a practitioner to make comprehensive engineering decisions considering risk, cost and benefit to justify including decisions for motorcyclists in the design process or when proposing treatment options in road safety audits or programs.

The report demonstrates that the design, and ongoing condition of the wearing course, in particular the surface friction, and advance warning, direction and curve quality/warning signage have a significant influence on motorcycle crash risk. The pavement technology and asset management Guides do not identify the needs of motorcyclists. The inclusion of information on motorcyclists, particularly with regard to identifying motorcyclist traffic volumes on lower order roads, and providing and maintaining a suitable standard of road infrastructure has the potential to significantly reduce motorcycle crash risk.

Safety benefit analysis

A safety benefit analysis case study was undertaken for a road in South Australia using the motorcycle model in AusRAP. The analysis took into consideration the following improvements on the midblock; delineation, curve quality, skid resistance, road condition, lane widening, sealed shoulder widening and sight distance. At intersections it took into consideration the inclusion of right turn lanes, channelisation and improvements to intersection design, advance warning, signing and markings (intersection quality).

An assessment was undertaken on an alignment with a pre-existing motorcycle crash history. The road is a mountainous rural connector road, approximately 35 km long, with posted speed limits of 60 km/h or less for 36% of the road and the remainder at 80 km/h, an AADT of 3100 and motorcycle daily flow of 110. There has been an average of 2.4 motorcyclist FSI crashes a year over a five year period.

The analysis showed that by treating the road infrastructure elements that affected crash likelihood, 18 FSI crashes could be prevented over 20 years with BCRs for each treatment ranging between 2 and 12. The treatments included improvements to skid resistance and road condition, delineation and curve delineation/curve quality, sight distance, sealed shoulder widening and lane widening.

The analysis showed that by treating the road infrastructure elements that affected crash severity, 12 FSI crashes could be prevented over 20 years with BCRs of three. The treatments included providing motorcycle safety barriers and clearing roadside hazards (where practicable).

9.2 Recommendations

It is recommended that the following general measures are considered by practitioners in safety, design, asset management, maintenance, pavement technology road engineering disciplines:

- Motorcyclists should be recognised as a unique road user group and have specific needs with regard to road infrastructure.
- The likelihood of a crash occurring and its likely severity are both important considerations, however with more focus on treating road infrastructure elements that affect likelihood further crash reductions can be achieved.
- It is perhaps more economical to treat road infrastructure elements that effect the likelihood of a crash occurring. Greater reductions in fatal or serious injury crashes (FSIs) may be achieved through a targeted focus on reducing the likelihood of a crash occurring as well as reducing the severity of a crash.
- As the proposed mitigation measures are road infrastructure based treatments, over time they can be integrated into existing practice and therefore existing funding.
- Motorcycle crash risk should be proactively identified and a remedial action program developed through motorcycle focused network safety assessments or road safety audits.

Proactive Road Assessment Programs (RAPs) such as the Australian National Risk Assessment Model (ANRAM), AusRAP and iRAP are recommended to be used to identify motorcycle crash risk during the design phase of new roads and on existing roads. Currently the motorcycle model is not active or reported in AusRAP assessments. It is recommended that based on the information in this report, the motorcycle model within AusRAP and ANRAM should be updated, and utilised in future assessments. The highest risk sections as identified in a RAP should be further investigated and undergo a motorcycle specific road safety audit, as developed by ARRB Group, to identify motorcycle high risk locations and provide site specific mitigation measures.

The proposed treatments within this report should be the focus of asset management programming and maintenance activities, particularly on roads with considerable motorcycle volumes or a significant motorcycle crash history. The key recommendations and proposed mitigation measures should be integrated in the Austroads Guides for each relevant road engineering discipline so as, over time, road infrastructure as a crash factor can be proactively reduced through good practice as well as reduced by remedial actions. A number of proposed changes to the Austroads Guides will require further research, the findings from the research if beneficial should be integrated into the relevant Guide.

It is recognised that a number of infrastructure mitigation treatment trials have been implemented in Australia and New Zealand using existing motorcycle safety guidance and shown to provide a reduction motorcycle risk and motorcyclist crashes. The proposed mitigation measures outlined, particularly those addressing trending crash types, should be investigated further and considered for trial and assessment. A trial of the mitigation measures would include incorporating treatments through existing programs and funding such as asset management and maintenance, and also through separate funding for remedial programs. The results of such trials may provide the evidence required to influence a change in industry practice, where practitioners in all road engineering disciplines, routinely cater for the needs of motorcyclists, thus proactively reducing the risk of road infrastructure being a factor in motorcycle crashes.

References

2-Be-Safe 2010, *Interaction between powered two-wheeler accidents and infrastructure*, 2-Be-Safe, EU, viewed 30 March 2016, <http://www.2besafe.eu/sites/default/files/deliverables/2BES_D2_RoadInfrastructureAndRoadSafetyForoursAndRoadSafetyForPTW.pdf>.

Australian Bureau of Statistics 2010, *Motor vehicle census, Australia, 31 March 2009*, ABS catalogue 9309, ABS, Canberra, ACT.

Australian Bureau of Statistics 2012, *Motor vehicle census, Australia, 31 January 2012,* ABS catalogue 9309, ABS, Canberra, ACT.

Australian Bureau of Statistics 2013, *Motor vehicle census, Australia, 31 January 2013*, ABS catalogue 9309, ABS, Canberra, ACT.

Allen, T, Day, L, Lenne, M, Symmons, M, Newstead, S, Hillard, P & McClure, R 2013, 'Finding evidence-based strategies to improve motorcycle safety: a case-control study on serious injury crashes in Victoria', *Australasian road safety research, policing and education conference, 2013, Brisbane, Queensland,* Australasian College of Road Safety, Canberra, ACT, 10 pp.

Anderson, C, Dua, A & Sapkota, J 2012, 'Motorcycle safety barrier trials in South Australia: case study: Adelaide Hills', *Australasian college of road safety conference, 2012, Sydney, New South Wales,* Australasian College of Road Safety, Canberra, ACT, 16 pp.

Australian Transport Council 2011, *National Road Safety Strategy: 2011-2020*, ATC, Canberra, ACT.

Austroads 1999, *Guide to traffic engineering practice: part 15: motorcycle safety*, AP-11.15-99, Austroads, Sydney, NSW.

Austroads 2008, *Guide to road safety part 9: roadside hazard management*, AGRS09-08, Austroads, Sydney, NSW.

Austroads 2009a, *Guide to asset management part 1: introduction to asset management*, AGAM01-09, Austroads, Sydney, NSW.

Austroads 2009b, *Guide to asset management part 5: pavement performance*, AGAM05-09, Austroads, Sydney, NSW.

Austroads 2009c, *Guide to road design part 6: roadside design, safety and barriers*, AGRD06-09, Austroads, Sydney, NSW.

Austroads 2010, *Guide to road design part 4A: unsignalised and signalised intersections*, AGRD04A-10, Austroads, Sydney, NSW.

Austroads 2012, *Improving roadside safety: stage 3: interim report*, AP-R419-12, Austroads, Sydney NSW.

Austroads 2013, *Guide to road design part 5A: drainage: road surface, networks, basins and subsurface*, AGRD05A-13, Austroads, Sydney, NSW.

Bambach, M & Grzebieta, R 2014, *Motorcycle crashes into roadside barriers: stage 4: protecting motorcyclists in collisions with roadside barriers*, University of New South Wales, Sydney, NSW.

Bambach, MR, Grzbebieta, RH, Tebecis, R & Friswell, R 2012, 'Crash characteristics and causal factors of motorcycle fatalities in Australia', *Australasian road safety research, policing and education conference, 2012, Wellington, New Zealand,* Ministry of Transport, Wellington, NZ.

Brennan, C & Beer, K 2007, ‘Motorcycle safety in Victoria: Black “spot” the difference’, *Australasian road safety research policing education conference, 2007, Melbourne, Victoria,* The Meeting Planners, Collingwood, Vic, 9 pp.

Cairney, P, Mitchell, B, Meyer, D, Van Dam, S & Makwasha, T 2015, *Evaluation of the Motorcycle Blackspot Program,* VicRoads, Kew, Vic.

Cossalter, V 2006, *Motorcycle dynamics*, Lulu, Morrisville, USA.

Davoodi, SR & Hamid, H 2013, ‘Motorcylist braking performance in stopping distance situations’, *Journal of Transportation Engineering*, vol. 139, no. 7, pp. 660-6.

de Rome, L & Brandon, T 2007, *A survey of motorcyclists in NSW, 2006: a report to the Motorcycle Council of NSW,* Motorcycle Council of NSW, Sydney, NSW.

Department of Infrastructure, Transport, Regional Development and Local Government 2008, *Fatal and serious road crashes involving motorcyclists*, Department of Infrastructure, Transport, Regional Development and Local Government, Canberra, ACT.

Department of Infrastructure and Transport 2013, *Road deaths Australia: 2012 statistical summary*, report INFRA 1421, Department of Infrastructure and Transport, Canberra, ACT.

Department of Main Roads 2006, *Road planning and design manual: chapter 13: intersections at grade*, TMR, Brisbane, Qld.

Department of Transport and Main Roads 2009, ‘Motorcycle mass action program: technical guidelines’, TMR, Brisbane, Qld.

Domhan, M 1987, ‘Guardrails and passive safety for motorcyclists’, *Vehicle highway infrastructure: safety compatibility,* Society of Automotive Engineers, Warrendale, PA, USA, pp. 205-8.

EuroRAP 2008, *Barriers to change: designing safe roads for motorcyclists*, EuroRAP, Basingstoke, Hampshire, UK.

FEMA 2012, *New standards for road restraint systems for motorcyclists: designing safer roads for motorcyclists*, Federation of European Motorcyclists’ Associations, viewed 30 March 2016, <http://www.fema-online.eu/guidelines/Guidelines.pdf>.

FHWA 2014, *Motorcycle safety*, Federal Highway Administration, Washington, DC, USA, viewed 30 March 2016, <http://safety.fhwa.dot.gov/motorcycles/>.

Green, D 2006 ‘A comparison of stopping distance performance for motorcycles equipped with ABS, CBS and conventional hydraulic brake systems’, *International motorcycle safety conference*, Long Beach, California, USA, 7 pp.

Grzebieta, R, Jama, H, Bambach, M, Friswell, R, McIntosh, A & Favand, J 2010, *Motorcycle crashes into roadside barriers stage 1: crash characteristics and causal factors*, NSW Injury Risk Management Research Centre (IRMRC), Sydney, NSW, viewed 30 March 2016, <http://www.tars.unsw.edu.au/downloads/Stage1_report.pdf>.

Henley, G & Harrison, J 2008, *Serious injury due to land transport accidents, Australia, 2005-2006,* Injury Research and Statistics Series no. 53, Australian Institute of Health and Welfare, Canberra, ACT.

Institute of Highway Engineers n.d., *Guidelines for motorcycling: road design & traffic engineering*, IHE, London, UK.

Institute of Highway Engineers n.d., *Guidelines for motorcycling: road maintenance*, IHE, London, UK.

Institute of Highway Engineers n.d., *Guidelines for motorcycling: road safety audit*, IHE, London, UK.

International Road Assessment Programme 2014, *Star rating score equations*, iRAP Methodology Fact Sheet 6, IRAP.

IRMRC 2010, Motorcycle crashes into roadside barriers. Stage 1: crash characteristics and causal factors, NSW Injury Risk Management Research Centre, viewed 5 Feb 2014, <http://www.tars.unsw.edu.au/downloads/Stage1_report.pdf>

Jost, K 2001, 'TRW develops active roll control', *Automotive Engineering International Online: Focus on Electronics*.

Khoo, J & Stevens, A 2011, 'Motorcycles on motorways', *Institution of Professional Engineers New Zealand (IPENZ) transportation conference, 2011, Auckland, New Zealand*, Harding Consultants, Christchurch, NZ, 8 pp.

Koch, H & Schueler, F 1987, 'Reduction of injury severity involving guardrails by the use of additional W-beams, impact attenuators and 'sigma-posts' as a contribution to the passive safety of motorcyclists', *International technical conference on experimental safety vehicles, 11th, 1987, Washington, DC, USA*, pp. 878-83.

Lindemann, M 2013, *The total motorcycling manual (cycle world): 291 skills you need,* Weldon Owen, San Francisco, CA, USA.

Milling, D & McTiernan, D 2014, 'Motorcycle road safety audit: Adelaide metro region', contract report, ARRB Group, Vermont South, Vic.

Motorcycle Council of NSW 2010, *Positioned for safety: a motorcycle safety strategic plan 2007-2010*, Motorcycle Council of NSW, Parramatta, NSW.

Motorcycle Council of NSW 2013, *Motorcycle crash data 2006-2010*, Motorcycle Council of NSW, Parramatta, NSW, viewed 30 March 2016, <http://roadsafety.mccofnsw.org.au/a/38.html>.

Motorcycle Safety Advisory Council 2014*, Making roads motorcycle friendly*, MSAC, New Zealand, viewed 30 March 2016, <http://msac.org.nz/assets/Uploads/pdf/Making-Roads-Motorcycle-Friendly-NZ-September-2014-V2.pdf>.

NZ Transport Agency 2012, *Safer journeys for motorcycling on New Zealand roads*, NZTA, Wellington, New Zealand.

Ouellet, JV 1982, 'Environmental hazards in motorcycle accidents', *American Association for Automotive Medicine (AAAM) annual conference, 26th, 1982, Ottawa, Ontario, Canada,* AAAM, Baltimore, Maryland, USA, pp. 117-29.

Pearson, R & Whittington, B 2001, 'Motorcycles and the road environment', *Insurance Commission of Western Australia conference on road safety, 2001, Perth, Western Australia,* Insurance Commission of Western Australia, Perth, WA, 20 pp.

Pieribattesti, F & Lescure, B 1999, 'New safety barriers better adapted to the restraint of motorcyclists', *Revue Generale des Routes*, no. 779, pp. 20-2.

Pointer, S 2013, *Trends in hospitalised injury, Australia 1999-00 to 2010-11*, AIHW, Canberra, ACT.

Roads & Maritime Services 2012, *Motorcycle ABS*, information sheet, Roads and Maritime, Sydney, NSW, viewed 30 March 2016, <http://www.rms.nsw.gov.au/documents/roads/licence/abs-motorcycles-brochure.pdf>.

Rogers, N 2008, 'Trends in motorcycle fleets worldwide', *OECD International workshop on motorcycling safety*, *Lillehammer, Norway,* OECD, viewed 14 April 2016, <http://www.itf-oecd.org/sites/default/files/docs/lillehammer08rogers.pdf>.

Roll, G, Hoffmann, O & Konig, J 2009, ‘Effectiveness evaluation of antilock brake systems (ABS) for motorcycles in real-world accident scenarios’, *International technical conference on the enhanced safety of vehicles, 21st, 2009, Stuttgart, Germany*, 12 pp.

Rumar, R 1999, ‘Speed: a sensitive matter for drivers’, *Nordic Road and Transport Research*, no. 1.

Scully, J, Newstead, S & Corben, B 2008, *Evaluation of the Motorcycle Blackspot Program*, report prepared for VicRoads, Monash University Accident Research Centre (MUARC), Clayton, Vic.

Thomas, A, Smart, W, de Roos, M, Webster, K & Gibbs, C 2011, ‘Motorcycle safety route review: a case study’, *Australasian road safety research, policing and education conference*, *2011, Perth, Western Australia*, Insurance Commission of Western Australia, Perth, WA, 10 pp.

Transport for NSW 2013, *Making roads more motorcycle friendly: a guide for road design, construction and maintenance*, TfNSW, Sydney, NSW.

VicRoads 2014, *Making roads motorcycle friendly: a guide for road design, construction and maintenance*, VicRoads, Kew, Vic, viewed 30 March 2016, <https://www.vicroads.vic.gov.au/~/media/files/technicaldocuments/guidelines/making-roads-motorcycle-friendly-december-2014.ashx vicroads making roads motorcycle friendly>.

Wood, B 2006 ‘Asset management, levels of service and motorcycle safety’, *Institute of Public Works Engineering Australia (IPWEA) New South Wales Division conference, 6th, 2006, Sydney, New South Wales*, IPWEA New South Wales Division, Sydney, NSW, 6 pp.

World Health Organization n.d., *Unit 2: risk factors for road traffic injuries*, WHO, Geneva, Switzerland, viewed 30 March 2016, <http://www.who.int/violence_injury_prevention/road_traffic/activities/roadsafety_training_manual_unit_2.pdf>.

Standards Australia

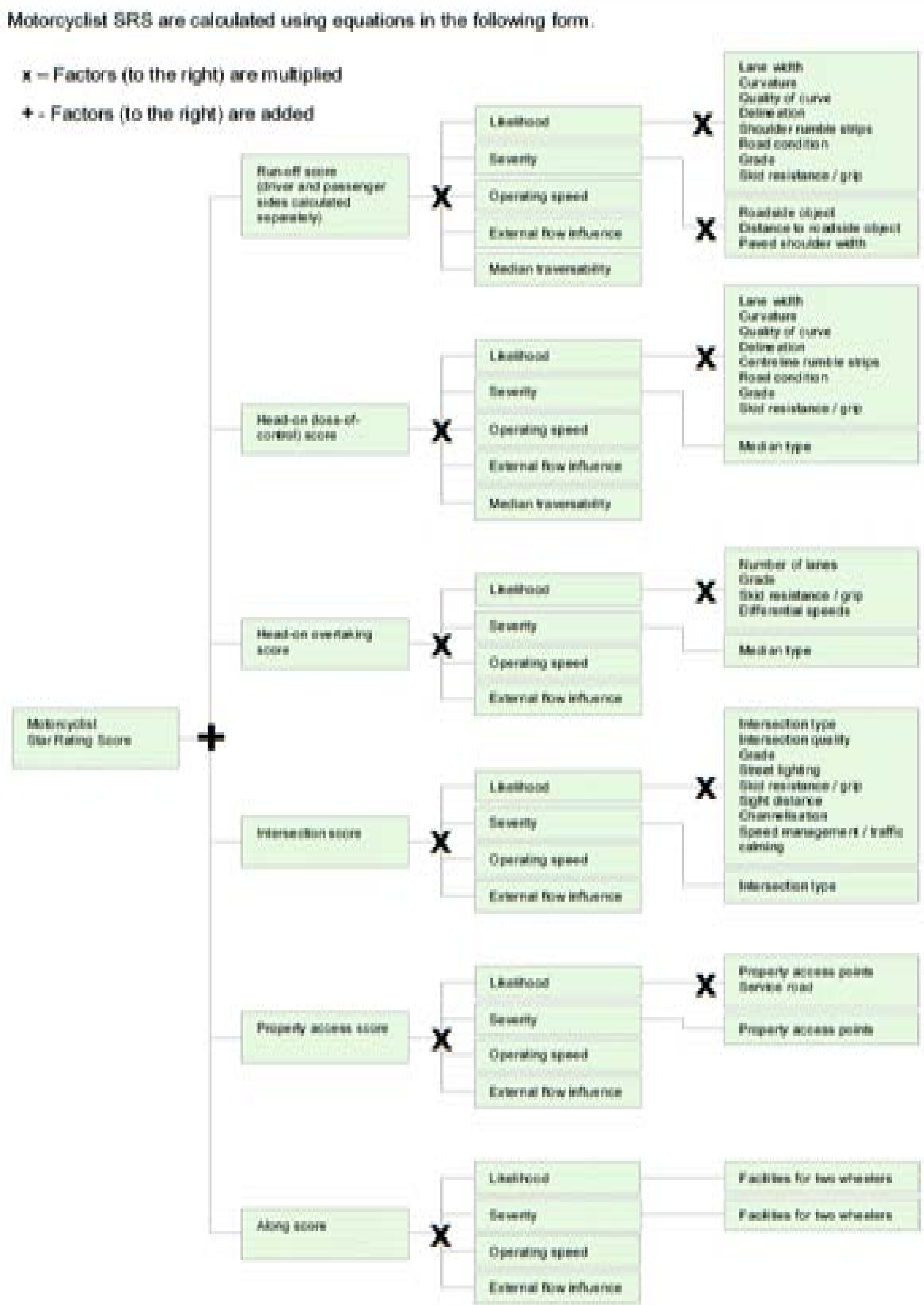
AS 1742.2–2009, *Manual of uniform traffic control devices: traffic control devices for general use*.

AS/NZS 3845-2015, Road safety barrier systems.

Appendix A AusRAP Star Rating Score (SRS) Risk Factors and Equation

A.1 Motorcycle Star Rating Score Equation

Figure A 1: Motorcycle star rating score equation



Source: International Road Assessment Programme (iRAP) (2014).

A.2 Risk Factors

Figure A 2: Motorcycle run-off road crash type infrastructure risk and safety risk score

Motorcycle crash type infrastructure risk

- Run-off Likelihood
  - Lane width
  - Curvature
  - Quality of curve
  - Delineation
  - Shoulder rumble strips
  - Road condition
  - Grade
  - Skid resistance / grip
- Run-off severity - driver-side
  - Roadside severity - driver-side distance
  - Roadside severity - driver-side object
  - Paved shoulder width driver-side
- Run-off severity - passenger-side
  - Roadside severity - passenger-side distance
  - Roadside severity - passenger-side object
  - Paved shoulder width passenger-side

Motorcycle star rating score (SRS)

- SRS - Run-off driver-side
  - Operating speed
  - Run-off likelihood
  - Run-off severity - driver-side
  - External flow influence - AADT per lane
  - Traversibility - run-off driver-side
- SRS - Run-off passenger-side
  - Operating speed
  - Run-off likelihood
  - Run-off severity - passenger-side
  - External flow influence - AADT per lane

Source: AusRAP test bed version 3.02, provided by iRAP (2014).

Figure A 3: Motorcycle head-on crash type infrastructure risk and safety risk score

Motorcycle crash type infrastructure risk

- Head-on LOC likelihood
  - Lane width
  - Curvature
  - Quality of curve
  - Delineation
  - Median rumble strips
  - Road condition
  - Grade
  - Skid resistance / grip
- Head-on LOC severity
  - Median type
- Head-on overtaking likelihood
  - Grade
  - Skid resistance / grip
  - Differential speed limits
  - Number of lanes
- Head-on overtaking severity
  - Median type

Motorcycle star rating score (SRS)

- SRS - Head-on lane departure
  - Operating speed
  - Head-on LOC likelihood
  - Head-on LOC severity
  - External flow influence - AADT per lane
  - Median traversibility - Head-on LOC
- SRS - Head-on overtaking
  - Operating speed
  - Head-on overtaking likelihood
  - Head-on overtaking severity
  - External flow influence - AADT per lane

Source: AusRAP test bed version 3.02, provided by iRAP (2014).

Figure A 4: Motorcycle intersection crash type infrastructure risk and safety risk score

Motorcycle crash type infrastructure risk	Motorcycle star rating score (SRS)
Intersection likelihood: Intersection type; Intersection quality; Grade; Street lighting; Skid resistance / grip; Sight distance; Channelisation - splitter and median islands; Speed management / traffic calming	SRS - Intersection: Operating speed; Intersection likelihood; Intersection severity; External flow influence - Side flow
Intersection severity: Intersection type	

Source: AusRAP test bed version 3.02, provided by iRAP (2014).

Figure A 5: Motorcycle property access crash type infrastructure risk and safety risk score

Motorcycle crash type infrastructure risk	Motorcycle star rating score (SRS)
Property access likelihood: Access points; Service road	SRS - Property access: Operating speed; Property access likelihood; Property access severity; External flow influence - Side flow
Property access severity: Access points	

Source: AusRAP test bed version 3.02, provided by iRAP (2014).

Figure A 6: Motorcycle midblock crash type infrastructure risk and safety risk score

Motorcycle crash type infrastructure risk	Motorcycle star rating score (SRS)
Along likelihood: Motorcycle facilities	SRS - Along: Operating speed; Along likelihood; Along severity; External flow influence - non M/C AADT per lane
Along severity: Motorcycle facilities	

Source: AusRAP test bed version 3.02, provided by iRAP (2014).

Appendix B Workshops and Consultations

B.1 Questionnaire Respondents

Table B 1: Questionnaire respondents

Name	Road agency or organisation	Position	Engineering discipline/unit
Brian Wood	Motorcycle Council of NSW	Secretary	Mechanical Engineer
George Formentin	Main Roads Western Australia (MRWA)	Road Safety Officer	Road Safety
Domenic Palumbo	MRWA	Director Metropolitan Operations	Asset Management and Maintenance
Jana Geisler	MRWA	Program Development Coordinator	Finance
Bruce Snook	MRWA	Principal Design Engineer	Road Design
Jon Gibson	Office of Road Safety WA	Policy and Strategy Director	Road Safety
Julian Chisnall	NZ Transport Agency	National Traffic and Safety Engineer	Road Safety Hardware and Design
Luke Rogers	iRAP	Senior Road Safety Engineer	Road Safety
Jen Woods	MRA ACT	President	Motorcycle Council Member
Nicky Hussey	MRA ACT	Secretary	Motorcycle Council Member
Ms Jayanthy Vikneson	Justice & Community Safety Directorate, ACT	Engineer – Road Safety	Road Safety
Mark McDonald	TMR	Senior Technologist (Bicycles, Pedestrians and Motorcycles)	Road Operations Engineering and Technology
Richard Bortko	VicRoads	Technical Leader – Senior Standards Engineer	Technical Services

B.2 Responses to Questionnaire

Table B 2: Questionnaire responses

Question 1: Do you agree with the preliminary findings? If not, please leave a comment and details as to why. Please provide any references to any publications if available.		
Literature review		MC NSW There is research which analyses motorcycle crashes by time of day and day of the week, such as the CARRS-Q report on motorcycle fatigue 'Research on fatigue to support the development of the NSW Motorcycle Safety Strategy' though I'm not aware of research that links the involvement of infrastructure in crashes versus time of day. NZTA No surprises in the findings, but concerned at the limitations in applicability to Safe System process and assessment of collective risk. Further work required to better define the identified risks in terms of personal and collective risk. No further comment or agreed to the preliminary findings: MRWA, MRA ACT, DPTI, ACT, TMR, VicRoads, iRAP.
Crash analysis	Midblock crashes	MC NSW Other research has also shown there are a high number of single vehicle midblock on straight crashes. A report by the City of Melbourne identified many of these are in the wet. iRAP It would be interesting to know if overtaking manoeuvres are a big issue and if so maybe physical median treatments might be an option. DPTI Are the crashes only casualty crashes? It is noted in our data that sometimes a motorcycle crash is recorded without injury but this seems almost unbelievable so it would just be useful to have the status of the data clarified. A more detailed look at crash severity in different settings may then be useful. Although 10 years of data has been used so you would not expect results to vary much by shifting the start year, data to 2011 is now starting to look a bit dated. Any trends over time in any of the jurisdictions would also be of interest, e.g. SA has been introducing various motorcycle safety interventions over recent years so any or no reflection in crash data might be useful. No further comment or agreed to the preliminary findings: MRWA, NZTA, MRA ACT, ACT, TMR, VicRoads.
	Intersection crashes	DPTI There was a 'higher' number of single vehicle crashes at intersections in QLD 'over the period'. Could this be due to sudden rainfall events catching riders unprepared? This could be analysed further. Also, the motorcycle intersection crashes in NZ were lower than SA/QLD – any comment on why this is the case? No further comment or agreed to the preliminary findings: MC NSW, MRWA, NZTA, iRAP, MRA ACT, ACT, TMR, VicRoads.

Question 1: Do you agree with the preliminary findings? If not, please leave a comment and details as to why. Please provide any references to any publications if available.		
Identification of contributory and causal factors	Midblock crash likelihood factors	MC NSW Further research is needed to better analyse single vehicle mid-block on straight crashes. iRAP Just thought I'd add a few comments from latest UK data for info. 65% of MC casualties occur on urban roads, 70% of MC fatalities occur on rural roads (speed probably playing a major role here). DPTI Will there be consideration of assessing maintenance regimes on motorcycle routes, particularly in relation to plant debris on the road and shoulder and the effect this has on crashes. No further comment or agreed to the preliminary findings: MRWA, NZTA, MRA ACT, ACT, TMR, VicRoads.
	Intersection crash likelihood factors	DPTI Please clarify what is meant by an intersection control method. Any indication of the % of good controls at intersections across the three states? No further comment or agreed to the preliminary findings: MC NSW, MRWA, NZTA, iRAP, MRA ACT, ACT, TMR, VicRoads.

Question 2: What additional comments do you have with regard to the preliminary findings? What have you noticed within your state?	
Literature review	NZTA No surprises in the findings, but concerned at the limitations in applicability to Safe System process and assessment of collective risk. Further work required to better define the identified risks in terms of personal and collective risk. iRAP Our figures (for GB) show that MCs make up less than 1% of traffic but 19% of fatalities (2013) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/359311/rrcgb-2013.pdf MRA ACT Crash data period of 2001 to 2011 may be considered somewhat out-of-date? It would be good to incorporate the most recent statistics available. No further comment or agreed to the preliminary findings: MC NSW, MRWA, DPTI, ACT, TMR, VicRoads.

Question 2: What additional comments do you have with regard to the preliminary findings? What have you noticed within your state?		
Crash analysis	Midblock crashes	MRWA The analysis of crash data (using QLD, SA and NZ data) presents similar results to that of a comprehensive analysis of motorcycle crashes in WA (five years of data 2009–13 looking at fatalities and serious injury). However, WA would suggest that this analysis could be further strengthened to include a comparison between metropolitan and regional motorcycle crashes as these are likely to have differences between crash types and road features and thus implications for different treatments. iRAP Slippery roads due to weather is significant factor in GB reported crashes (7%). DPTI The differences in percentages on curves between jurisdictions are worth pondering. Local motorcycle travel geography must be a factor. ACT Total no. of motorcycle crashes in the ACT in the last five years (2009–13) was 1 264. This is about 3% of the total no. of on-road crashes in the ACT. Of these 1 264 motorcycle crashes, 46% occurred in midblocks and 54% occurred at intersections. 64% were multiple-vehicle crashes and 36% were single-vehicle crashes. TMR Dr Angela Watson in CARRS-Q has recently completed some important work on unreported crashes. She found police crash data significantly under-reports hospitalisation crashes for motorcycles and bicycles. For those admitted to hospital 65% of motorcyclist injuries are possibly not reported. For those involving another vehicle, 59% may be not reported and for those not involving another vehicle, 71% may not be reported. For cyclists the difference is more obvious. Overall, 80% of admitted cyclist injuries may be unreported. For those involving another vehicle, 68% may not be reported and for those not involving another vehicle 95% may not be reported. By contrast - the potential under-reporting for drivers is 17%, 15% for those involving another vehicle and 23% for those not involving another vehicle. This may be a point of contrast, that despite the possible hospital coding issues, it still means there is a clear issue for cyclists and motorcyclists. The ratio of unreported crashes involving another vehicle is astonishing, I have not queried Angela about the relative injury severity of unreported vs reported hospitalisations. This may be important information to consider in your crash data analysis. No further comment or agreed to the preliminary findings: MC NSW, NZTA, MRA ACT, VicRoads.
	Intersection crashes	DPTI The higher ratio for commuting multiple vehicle crashes at roundabouts in QLD and SA relative to NZ and single vehicle crashes is noted and needs further investigation. No further comment or agreed to the preliminary findings: MC NSW, MRWA, NZTA, iRAP, MRA ACT, ACT, TMR, VicRoads.
Identification of contributory and causal factors	Midblock crash likelihood factors	Refer to Section 4.4.
	Intersection crash likelihood factors	Refer to Section 4.5.

Question 3: Does your state have any technical guidelines targeted to catering for motorcycles? **If so please list them and if possible provide a link or a PDF. This does not include information/ awareness documents.**
MC NSW Transport for NSW (2013) '*making roads more motorcycle friendly*' October 2013 http://roadsafety.transport.nsw.gov.au/downloads/motorcyclists/makingroads_motorcyclefriendly_oct2013.pdf NZTA Two documents of specific application for motorcyclists: Safer journeys for motorcycling on New Zealand roads (NZTA, link: http://www.nzta.govt.nz/resources/safer-journeys-motorcyclists). Making roads motorcycle friendly (Motorcycle Safety Advisory Council MSAC publication, link: http://msac.org.nz/assets/Uploads/pdf/Making-Roads-Motorcycle-Friendly-NZ-September-2014-V2.pdf). iRAP http://www.motorcycleguidelines.org.uk/the-guidelines/introduction.

Question 4: Excluding mass action programs does your state currently specifically cater for motorcycles? **Is the percentage of motorcycles considered?**		
Road design	Intersection or midblock design, lane or shoulder locations of fixed surface hazards (service covers, tram lines, bridge joints), road surface type and performance (pavers, concrete, asphalt, chip seal), kerb profiles etc.	NZTA Working with sector through MSAC. Looking into development of an instrumented motorcycle, plus assessing current asset data collection techniques (SCRIM and laser roughness) to see if more motorcycle centric information can be gathered or derived. MRA ACT Not that we are aware, although we have often been asked to provide feedback into road infrastructure changes/plans – mostly changes, new intersections etc. DPTI Not explicitly but it is left to the designer to consider or road safety audit as prescribed. The percentage would not be considered with the exception of barrier choice in which case the barrier type or at least the under-rail protection (motorcycle steel rail under guard rail and crash cushions on wire rope fence posts). ACT All road designs take into consideration the needs of motorcycles.

Question 4: Excluding mass action programs does your state currently specifically cater for motorcycles? Is the percentage of motorcycles considered?		
Asset management	Assignment of funds on roads with high % of motorcycles to target directional and warning signage, maintain road surface quality etc.	MRWA Not specifically for motorcycles. NZTA Working with sector through MSAC. MRA ACT Not that we are aware. Problems we encounter in the ACT specific to motorcyclists: (1) Vegetation control/removal. (2) Dirt and debris on roads. (3) Rutting, shoving and other deformities. See comments on midblock worksheet. We are also concerned about: (a) The effect of government budget constraints on road infrastructure asset management / maintenance programs. (b) Whether there is sufficient oversight/audit of asset management and maintenance programs to identify poor performance and enforce improvement/rectification. DPTI ARRB, on behalf of DPTI (SA), has undertaken special road safety audits of identified higher risk motorcycle routes and assigned funds to improve road and roadside features for motorcycling. The number and severity of motorcycle crashes are key criteria, rather than motorcycles as a percentage of traffic volume. ACT Motorcycles are considered a standard vehicle. No separate fund allocations for motorcycle needs only.
Maintenance	Contractual obligations with regards to motorcycle specific intervention levels and quality of workmanship etc.	MRWA Budgeting split into three main areas: general, electrical devices, surfacing. Nothing specific to motorcycles. NZTA Working with sector through MSAC. DPTI No – relies on observation or feedback from community and action by individual professionals. The percentage would not be considered in this case. DPTI are in the process of working with the asset maintenance group in consideration of weighting motorcycle crashes in regard to pavement condition.

Question 5: After reading the preliminary findings has your awareness of contributory and causal factors that contribute towards the likelihood of a motorcycle crash improved? Do you agree that a combination of contributory or causal factors at one location increases the likelihood of a motorcycle crash?
NZTA No as I work in this space. MRA ACT The preliminary findings bear out the experiences of local riders. DPTI Yes to both questions, this is also the case for vehicles and drivers in general, and is somewhat related to the 'swiss cheese' concept (which includes non-infrastructure factors as well, and requires holes in the slices of Swiss cheese to line up for an impending event to get through). MC NSW, MRWA, iRAP, ACT, TMR, VicRoads indicated that their awareness has increased and they agreed that the combination of contributory or causal factors at one location increase the likelihood of a motorcycle crash.

Table B 3: Midblock crash likelihood – contributory and causal factors affecting crash likelihood – responses

Midblock – road design or infrastructure element group	Description (ARRB)	Response (stakeholder)
Sight distance	Good sight distance allows a rider to identify and safely negotiate the upcoming road alignment, a hazard or deficiency on the road or a vehicle that has crossed the centre line. If any of these come as a surprise to a rider emergency braking and weaving may be required, this increases the risk of the bike destabilising and a crash occurring. The rider may not see a road surface deficiency or hazard, traversing it may redirect the path of the bike or destabilise it. Similarly a rider may not identify another user early enough to avoid the conflict point, resulting in a multiple vehicle crash.	MRA ACT Vegetation control / removal. Mowing or slashing a narrow strip one metre wide on each side of the road does very little to improve vision through corners. This is particularly important on the approaches to intersections and around property entrances. Tall grass and the accompanying scrub should be trimmed back more aggressively to improve vision. More education for road maintenance staff may help. No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, NZTA, iRAP, ACT, TMR, VicRoads.

Midblock – road design or infrastructure element group	Description (ARRB)	Response (stakeholder)
Road alignment	**Horizontal** – A motorcycle is required to use the full width of the lane and lean the bike over whilst navigating a curve, this reduces the ability to brake heavily and redirect the riding path and is more prevalent on a reverse or compound curve. On a curve the motorcycle is highly reliant on a smooth, consistent and debris free road surface with adequate surface texture to remain upright. If one or more are not present the likelihood of a crash increases. An errant motorcycle on a curve is likely to continue on a tangent into the opposing lane (left curve) and shoulder (right curve). A rider that selects a riding path close to the centre line on a right curve is at risk of a head-on crash, particularly leaning on a small radius curve, with narrow lanes. A repetition of curves increases the likelihood of an error, particularly when closely spaced (reverse curve). **Vertical** – steep downgrades result in braking and turning being a laborious task physically and mentally, errors can easily occur. The risk in increased in wet conditions due to the effects of surface texture or perceived surface texture (more in travel lane surface texture).	MC NSW A motorcycle isn't required to use the full width of a lane, even at extreme lean angles it wouldn't use the full width of the lane. It can however position itself anywhere within a lane to navigate a curve. A rider close to the centre line is at risk of a head-on crash, similarly a rider close to the edge line on a left curve is at risk of impacting poles and posts. MRWA The design principle of road building to refrain from straight roads to keep drivers occupied and alert seems to be inconsistent with safety for motorcyclists. In WA we have seen many rural single vehicle fatalities where riders have failed to negotiate a medium or high speed bend and gone wide off the road. On close inspection it has been observed that the angle of superelevation tapers off towards the edge of the seal. Some of these locations were right hand bends that had been treated with a seal widening. The widened perimeter often has less superelevation. A rider already struggling to reduce their radius of turn will find it even harder when riding across the outer edge with reduced superelevation. No further comment or agreed to the preliminary findings: MC NSW, MRWA, iRAP, ACT, TMR, VicRoads. The following road agencies had no further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, NZTA, iRAP, MRA ACT, ACT, TMR, VicRoads.
Travel period and traffic volume	During the commuting period, typical traffic volumes are higher. On multilane roads this increases the likelihood of a multivehicle crash (side-swipe, change lane etc.). On single lane roads this increases congestion, mainly on rural connector roads, placing an emphasis on overtaking provisions to reduce the likelihood of risky overtaking manoeuvres.	MRWA Pot holes are not much of an issue for WA. Crack sealing and patching are the main issues for Local Government. NZTA Also similar crash risk issues arise with filtering (lane splitting) manoeuvres where legal. No further comment or agreed to the preliminary findings: MC NSW, DPTI, iRAP, MRA ACT, ACT, TMR, VicRoads.

Midblock – road design or infrastructure element group	Description (ARRB)	Response (stakeholder)
Travel lane surface texture, condition and hazards	The travel lane surface condition influences the ability of motorcycles to maintain a riding path, effectively brake and maintain traction on curves. The surface texture or perceived surface texture (namely asphalt in the wet) and changing surface textures have an effect on the stability of a motorcycle on a curve and affects the stopping distance. Material on the road such as plant debris, gravel, fuel/oil, crack sealant, steel service covers and bridge joins causes a loss of grip between tyre and the road surface. Hazards on the road such as potholes, ruts, construction and patch repair joins, depressed or raised service pit covers and shoving will result in a rider heavily braking and redirecting the bike introducing the likelihood of loss of control, or if struck may redirect the riding path of the motorcycle.	MC NSW Shoving is mentioned, how about longitudinal rutting which is particularly hazardous on curves as it causes a motorcycle to go off line as the bikes surfs down the side of the rut. NZTA Also major seal joins between surfacing runs. These should be positioned well before a curve or braking area to give a rider opportunity to react/respond appropriately. iRAP Key highway maintenance role here to keep running lane free of hazards and debris and also to ensure appropriate skidding resistance particularly at high risk locations (curves and junction approaches). Worn/polished inspection covers have a low skid resistance and cause problems in the vehicle path and in braking zones. MRA ACT Dirt and debris on roads. This is more prevalent where dirt roads join sealed roads or property driveways join a road. Dirt and gravel is washed onto roads during heavy rain with reduced grip for riders particularly on corners. Some realignment of adjoining dirt roads and driveways and improved drainage of these will eliminate most of this. Tree and plant litter has a similar effect. Older ACT suburbs have established deciduous trees so wet tree litter can be a hazard. Regular road sweeping, and tree trimming or removal will all help. Finally, loose gravel is often left on newly chip and sealed sections of road and not always monitored or promptly swept up. Rutting, shoving and other deformities are more prevalent after rain or the cold ACT winter weather and sometimes result from constant heavy vehicle traffic. The deformities can be very unsettling for motorcycles, particularly mid-corner. More education for road maintenance personnel will help. No further comment or agreed to the preliminary findings: DPTI, MRWA, ACT, TMR, VicRoads.

Midblock – road design or infrastructure element group	Description (ARRB)	Response (stakeholder)
Shoulder surface hazards	A hazard on a sealed shoulder reduces the usable formation width, resulting in a reduced recovery width for an errant motorcycle. Loose material on the shoulder is hazardous to an errant motorcycle that may be braking heavily. Overgrown grass on the shoulder blocks delineation on guard rail or guide posts.	NZTA Unsealed shoulders are a known hazard. Sealing shoulders to the face of the barrier increases recovery space. iRAP I think well-maintained paved shoulders are an important safety feature. No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, MRA ACT, ACT, TMR, VicRoads.
Formation width	A wide lane allows a rider to select a safe riding path whilst maintaining a buffer to vehicles in the opposing lane (left curve) or the shoulder (right curve). This buffer is particularly important on curves and is known as the 'head-on zone'.	NZTA Wide lanes are not necessarily an improvement if the motorcyclist positions at the extremities of the lane to maximise sightlines and/or entry/exit speed. Some form of separation is also important, such as flush median (urban) or wide centreline (rural). iRAP Could wider lanes encourage higher operating speeds? If so, does that negate the benefits? MRA ACT The ACT Government has been introducing on-road bicycle lanes in more recent years, which often has the effect of reducing lane width for remaining vehicles and has the knock-on effect of reducing buffer zones. No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, ACT, TMR, VicRoads.
	The shoulder provides additional width for an errant motorcycle to recover if it leaves the lane (notably on a right curve). It can also act as additional lane width to use if evasive action is required to avoid a surface hazard or vehicle.	NZTA Shoulders only improve safety if sealed. Unsealed shoulders are a hazard. No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, iRAP, MRA ACT, ACT, TMR, VicRoads.
	The width of the shoulder affects the likelihood of a motorcyclist striking a safety barrier or sign or power pole on the edge of the formation.	No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, NZTA, iRAP, MRA ACT, ACT, TMR, VicRoads.

Midblock – road design or infrastructure element group	Description (ARRB)	Response (stakeholder)
Signage and delineation	Signage and delineation provide information that allows a rider to make safe and informed decisions about travel speed and riding path selection. This reduces the need for heavy braking and re-directive manoeuvres which increase crash risk.	iRAP Vehicle activated signs have been reasonably effective particularly where speeds are high on approaches to bends or at village gateways http://webarchive.nationalarchives.gov.uk/20120606202850/http:/assets.dft.gov.uk/publications/tal-1-03/tal-1-03.pdf. MRA ACT Whilst we acknowledge that informative road signage can assist riders, excessive road signage can distract or confuse, plus becomes an additional roadside hazard. In urban areas of the ACT there is a plethora of non-road safety signage. No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, NZTA, ACT, TMR, VicRoads.
Curve quality	Guide posts, edge lines and centre lines are used by a rider to predict the upcoming alignment. On high speed, low radius curves (moderate to sharp curves) the motorcycle is leant over, edge lines (left curve) and centre lines (right curve) are used by a rider to follow the alignment. This is due to the rider scanning the road surface for hazards and the guideposts being outside the field of vision.	iRAP Posts must be frangible. No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, NZTA, MRA ACT, ACT, TMR, VicRoads.
Average speed and overtaking provisions	Inadequate overtaking provisions such as; frequent passing lanes, stopping bays, inadequate lengths of broken barrier line (too short to safely overtake using the opposing lane), result in rider frustration, particularly when the terrain is such that a motorcycle would have a faster average speed (within the speed limit) than that of other vehicles. This leads to unsafe overtaking manoeuvres at legal and illegal overtaking locations.	MRA ACT Not of particular concern in the ACT, although it is a problem when travelling into neighbouring NSW. No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, NZTA, iRAP, ACT, TMR, VicRoads.
Roadworks	Road works introduce a number of hazards to motorcyclists, these include steel plates over trenches, longitudinal grooves from roto-milling, differences in road surface height creating longitudinal and perpendicular ledges, long temporary kerbing may not be attached securely or delineated, and raised reflective pavement markers may be in the centre of a temporary lane.	MRWA Maintaining high standards at long term road works are not always adopted by agencies, particularly utilities. NZTA Appropriate signage of roadworks important. Temporary signage must also be positioned appropriately to allow time to respond to the messages. MRA ACT See comments regarding dirt and debris on roads, above.

Midblock – road design or infrastructure element group	Description (ARRB)	Response (stakeholder)
Combination of factors	At a location where there are a number of factors the riding task becomes complex, a rider may misread the alignment, the road environment may not allow a motorcycle to safely negotiate a chosen riding path, undergo heavy braking or evasive re-directive manoeuvres.	No further comment or agreed to the preliminary findings MC NSW, DPTI, MRWA, NZTA, iRAP, MRA ACT, ACT, TMR, VicRoads.
Additional comments		
Safety barriers	MRA ACT The design of barriers is an area where we feel motorcyclists are not adequately considered, or perhaps the cost of motorcycle-friendly barriers are deemed too expensive. The installation of rub-rails are an example of a treatment that improves barriers for motorcyclists in the event of a crash, but there are none installed in the ACT.	
Road safety barriers Delineation Roadside hazards Speed humps (MC NSW)	All types of roadside safety barriers are likely to cause serious injury to a motorcyclist. When specifying roadside safety barriers the 'no barrier option' and barriers with motorcycle friendly features should be considered in the analysis. Delineation devices such as pavement blocks, raised pavement markers, Swarflex lane dividers and Vibraline can destabilise a motorcycle. Their use should be limited to areas unlikely to be impacted by a motorcycle. Roadside furniture needs to be positioned to reduce the likelihood of an errant rider impacting it. Lighting poles should be positioned away from the kerb. The number of poles and posts can be minimised by mounting several signs on the one pole or post. Supporting structures for traffic signal lanterns should be designed so the structure is positioned away from the roadway. Speed humps and raised platforms need to be well-delineated so they don't come as a surprise to a rider.	
Treatment of hazards (MRWA)	There are many hazards within the road reserve which do not present serious harm to motorists but can be a significant potential hazard to motorcyclists. Placement, visibility and treatment of these potential hazards can considerably reduce the likelihood or effect of colliding with the hazard. For example, in WA we have fatalities where motorcyclists strike the nose of raised median islands. Many of these instances occur during low light conditions. It is felt that by improving the visibility of the leading edge of raised median islands, e.g. with high visibility/retro-reflective paint, that many of these incidents could be prevented. This is particularly relevant in unlit locations where delineation is not complete. Alternatively, painted (not raised) islands could be recommended where a raised island is not imperative.	
Road safety barriers (NZTA)	Recent research Grzebieta et al. (2010), has demonstrated the benefits for appropriately designed road safety barrier systems to reduce motorcyclist injury and improve safety outcomes. Addition of motorcyclist protection systems, whether continuous (rub rails) or discontinuous (post buffers) will depend on the road safety barrier system This is not well covered in the road safety barrier standard (AS/NZS 3845-2015) but this is being addressed in the revision of the Standard.	

Midblock – road design or infrastructure element group	Description (ARRB)	Response (stakeholder)
Lighting (NZTA)	Improves the opportunity for motorcyclists to identify risks and objects on the road surface. Modern LED road lighting is a significant improvement on current high pressure sodium or mercury vapour luminaires. Appropriate lighting design to achieve good levels of illuminance and uniformity is important.	

Table B 4: Intersection crash likelihood: contributory and causal factors affecting crash likelihood – responses

Intersection – road design or infrastructure element group	Description (ARRB)	Response (stakeholder)
Visibility	Motorcycles are susceptible to not being seen at intersections when on the through road or waiting in the queue or through or side road to turn.	iRAP What about night-time visibility? Need for street lighting at some locations? No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, NZTA, MRA ACT, ACT, TMR, VicRoads.
	The presence of motorcycle on the through road is less conspicuous when the intersection is located on or over a crest and on the inside of a curve.	No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, NZTA, iRAP, MRA ACT, ACT, TMR, VicRoads.

Intersection – road design or infrastructure element group	Description (ARRB)	Response (stakeholder)
Intersection type	Roundabouts – adverse crossfall on curves, surface water from blocked central island drains and irrigation systems. A motorcycle is required to accelerate on the curve which is risky when surface grip is not available, particularly on an adverse crossfall. Entry and exit design speeds on roundabouts are designed for vehicles, they will not by design reduce the speed of a motorcycle. Sight lines are designed assuming a motorist will slow and yield at the roundabout entry, a motorcycle can approach at speed and continue through the roundabout at speed, as can a vehicle on multilane roundabouts.	MC NSW Vegetation in the middle of roundabouts can restrict the line of sight of vehicles approaching the roundabout. MRWA In situations where construction costs are constrained or BCR needs to be positive then conversion of intersections to roundabouts can result in considerable slope change at entry and exit transition points. Where funds are available the land around the roundabout is re levelled so that transition crossfalls are reconstructed on all approach and exit points. The deflection design for roundabouts is for passenger vehicles, not for motorcycles. There are no design standards to ensure deflection for motorcycles. NZTA Kerbed or raised central islands in roundabouts are a risk to motorcyclists whose general line through this form of intersection is straighter than that of a car or truck. Planting within the central island can obscure motorcyclists from other road users. MRA ACT The ACT has a large number of roundabouts and the camber on some (and their approach roads) not only affects grip, but also adds an extra distraction for riders when they have much to process already. No further comment or agreed to the preliminary findings: DPTI, iRAP, ACT, TMR, VicRoads.
	T-intersection – this intersection has fewer conflict points then a cross-intersection however the turning manoeuvres are less complex. As a result vehicles often turn at speed whilst only glancing to check for vehicles, a motorcycle is less likely to be seen.	NZTA High probability of high severity crashes for motorcyclists (and cars). iRAP Turn lanes to be encouraged. No further comment or agreed to the preliminary findings MC NSW, DPTI, MRWA, MRA ACT, ACT, TMR, VicRoads.

Intersection – road design or infrastructure element group	**Description (ARRB)**	**Response (stakeholder)**
	Cross-intersection – the issues for a motorcyclist are the same as for vehicle crashes	NZTA High probability of high severity crashes for motorcyclists (and cars). iRAP Turn lanes to be encouraged. No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, MRA ACT, ACT, TMR, VicRoads.
	Centre median – a centre median along a midblock section is likely to have debris in it, may not be wide enough for a motorcycle to store or stop midway through a U-turn manoeuvre.	No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, NZTA, iRAP, MRA ACT, ACT, TMR, VicRoads.
Turning provisions	A motorcycle making a right turn from the through road or side road at an unsignalised or signalised filter right turn is left exposed to through traffic.	No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, NZTA, iRAP, MRA ACT, ACT, TMR, VicRoads.
	Motorcycles may not be identified on a through road by a motorist making a right turn on a right filter or signalised right turn.	No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, NZTA, iRAP, MRA ACT, ACT, TMR, VicRoads.
	Motorcyclists may not be seen when in the inside lane of a dual lane turn and cut off by a vehicle that crosses the continuity/turn line markings.	No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, NZTA, iRAP, MRA ACT, ACT, TMR, VicRoads.
Horizontal geometry	Due to the braking and handling characteristics of a motorcycle an intersection conflict point located on a curve (through road, slip lane or roundabout) is more difficult for a motorcycle to evade and stay upright.	No further comment or agreed to the preliminary findings: MC NSW, DPTI, MRWA, NZTA, iRAP, MRA ACT, ACT, TMR, VicRoads.
Advance signage	A lack of advance directional or warning signage or unclear or cluttered signage does not allow a motorcycle to identify an upcoming intersection. This may lead to heavy braking, lane changes or re-directive manoeuvres which all introduce crash risk.	MRWA Much of the WA network was constructed under old standards. Many local roads have too many signs at junctions, many of which are poorly positioned due to utilisation of existing poles and insufficient advance signage. MRA ACT As for midblock response. No further comment or agreed to the preliminary findings MC NSW, DPTI, NZTA, iRAP, ACT, TMR, VicRoads.

Intersection – road design or infrastructure element group	Description (ARRB)	Response (stakeholder)
Line of sight	Safe intersection and approach sight distance allow a motorcyclist to reduce speed to yield or scan for a vehicle. Depending on the road surface condition and the motorcycle's braking technology and riders experience the design stopping distance may not be sufficient to avoid a conflict. If the line of sight does not provide the minimal distance as per design standards the risk of loss of control or a collision with another vehicle is increased.	NZTA Sight distance calculations are not necessary calculated for motorcycles. MRA ACT As for midblock response. DPTI DPTI will commence a trial of transverse line marking on the approach to a T-junction, where line of sight is poor. DPTI will measure speeds of motorcycles and vehicles before and after the treatment. No further comment or agreed to the preliminary findings MC NSW, MRWA, iRAP, ACT, TMR, VicRoads.
Travel lane surface texture, condition and hazards	The issues are the same as for the midblock however they are more critical in the event a braking or re-directive manoeuvre is being undertaken to avoid a collision.	MRA ACT As for midblock response. No further comment or agreed to the preliminary findings MC NSW, DPTI, MRWA, NZTA, iRAP, ACT, TMR, VicRoads.
Carriageway width	A wide lane and shoulder will provide more manoeuvring width for a motorcycle to avoid a collision.	The following road agencies had no further comment or agreed to the preliminary findings MC NSW, DPTI, MRWA, NZTA, iRAP, MRA ACT, ACT, TMR, VicRoads.
Additional comments		
Pavement markings	MC NSW Pavement markings need to have high levels of skid resistance to reduce the likelihood of motorcycles skidding when braking or accelerating.	
Lane filtering	Intersection rear-end crashes – lane filtering and advance storage areas for motorcycles.	

B.3 Workshop Attendees

Table B 5: Workshop Attendees

Name	Organisation	Position	Engineering discipline/unit
Warren Blandy	VicRoads	Network Programs Officer (Network Safety)	Network Programs
Richard Bortko	VicRoads	Technical Leader – Senior Standards Engineer VicRoads	Technical Services
Sagar Dhamala	TMR	IAP Civil Engineering Student	Traffic Engineering Practice
Alex Duerden	DPTI	Road Safety Engineering Unit Manager	Safety and Policy Programs
Jon Gibson	MRWA	Special Projects	Office of Road Safety
Siva Jeevaratnam	TMR	Traffic Engineering Practice	Civil engineer
Shaun Lennard	Australian Motorcycle Council	Chairman	Safety (motorcycle)
Mark McDonald	TMR	Senior Technologist (Bicycles, Pedestrians and Motorcycles)	Road operations
Santosh Tripathi	TMR	Principal Engineer (Road Safety)	Safer Roads
Noel O'Callaghan	DPTI	Principal Road Design Engineer	Safety and Service

Austroads

Level 9, 287 Elizabeth Street
Sydney NSW 2000 Australia

Phone: +61 2 8265 3300

austroads@austroads.com.au
www.austroads.com.au