

CURRENT TRENDS IN MOTORCYCLE- RELATED CRASH AND INJURY RISK IN AUSTRALIA BY MOTORCYCLE TYPE AND ATTRIBUTES



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CURRENT TRENDS IN MOTORCYCLE-RELATED CRASH AND INJURY RISK IN AUSTRALIA BY MOTORCYCLE TYPE AND ATTRIBUTES

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Abstract:

The purpose of this study was to characterise current and future motorcycle related road trauma to guide effective safety interventions and future research. Police reported crash data for South Australia, Western Australia, Queensland, Victoria and New South Wales and registration data for Victoria and New South Wales for the years 2005 to 2014 were matched with Redbook model types and Road Vehicle Certification Scheme (RVCS) motorcycle characteristic data after decoding models from vehicle identification numbers. These data sources were combined to analyse trends by attributes for injury crashes, registered vehicles and crash rates per registered vehicle. Analysis also considered the odds of a fatal or serious injury outcome given involvement in an injury crash.

Average crash risks per registered motorcycle were 1% per year for injury crashes and 0.5% per year for a fatal or serious injury crashes with just under half of all reported motorcycle injury crashes resulting in fatal and serious injuries, around twice the rate for cars. Injury crashes in rural and remote regions occurred at higher proportions than expected. Thirty-five percent of injury crashes (and 40% of fatal and serious injury crashes) were in rural or remote regions and just under 30% (and just over 30% for fatal and serious injury crashes) occurred in speed zones of 80 km/hr or more. The odds of a more serious injury crash were 48% higher if the crash region was remote (relative to rural). Over 50% of motorcycle injury crashes were multi-vehicle and outcomes for this crash type were more likely to be fatal and serious than for single vehicle crashes. For the 20% of injury crashes which involved one vehicle turning in front of another, the odds of a more severe outcome were about twice that for a single vehicle injury crash. Single vehicle crashes had 30% lower odds of a more serious injury outcome if the vehicle remained on the carriageway. While the proportion injury crashes involving older riders (60+ years) was small, this proportion doubled over 10 years (to 7%) and their injury outcomes were poorer.

A unique feature of the study was the ability to study factors affecting crash risk and injury outcomes for motorcyclists related to motorcycle type and other attributes including engine capacity and power to weight ratio. Crash rates and injury outcomes varied significantly by motorcycle type. Furthermore, those motorcycle types with the highest crash risk and highest risk of serious injury outcomes, namely sports motorcycles, are becoming more prevalent in the fleet, which is adversely affecting motorcycle safety. Further adverse effects on motorcycle safety are stemming from the trend to increasing power to weight ratio of newer motorcycles, which has shown a significant association with more severe injury outcomes in a crash. Analysis results also suggest that the effectiveness of the LAMS criteria could also be improved by considering motorcycle type in the restriction criteria.

Suggested countermeasures include addressing motorcyclist conspicuity and vulnerability, reduced speed limits where appropriate in higher speed zones and remote areas, licensing and speed enforcement, vehicle safety technologies and motorcyclist focussed road infrastructure improvements.

Key Words:
Disclaimer

Motorcycle injury crash risk Vehicle characteristics, LAMS, type, Countermeasures	This report is disseminated in the interest of information exchange. The views expressed here are those of the authors, and not necessarily those of Monash University
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- Laurie Budd: Assembly, analysis design, preparation and statistical analysis of datasets and first draft of report

Ethics Statement

Ethics approval was not required for this project.

CONTENTS

CONTENTS	5
FIGURES	7
TABLES	9
ACKNOWLEDGMENTS	10
EXECUTIVE SUMMARY	11
PART 1 INTRODUCTION	17
PART 2 DATA	18
2.1 RVCS and Redbook data	18
2.2 Registration data.....	18
2.3 Crash data	19
PART 3 METHODOLOGY	21
3.1 Crash covariates used in crash severity analyses.....	23
PART 4 RESULTS	25
4.1 Summary – Descriptive Analysis	25
4.2 Summary – Logistic Regression Analysis	27
4.3 Changes in registrations (VIC and NSW) and injury crash rates and risk over time.....	31
4.4 Effects of jurisdiction	35
4.5 Effects of year of manufacture	35
4.6 Effect of engine size	43
4.7 Effect of power-to-weight ratio	47
4.8 Effect of LAMS status	50
4.9 Effect of Redbook type	51
4.10 Effect of engine capacity and Redbook type	55
4.11 Effect of rider attributes.....	56
4.12 Effect of crash location	63
4.13 Effect of crash conditions.....	68
4.14 Effect of crash types	71
PART 5 DISCUSSION	77
5.1 Limitations of using registrations as the measure of exposure	77
5.2 Overall trends in crashes and crash/crash severity risk	77
5.3 Multi-vehicle crashes	78
5.4 Single-vehicle crashes	79
5.5 Overall trends in motorcycle attributes: registrations and risk	80
5.6 Safest motorcycle types.....	80
5.7 Least Safe Motorcycle Types	81
5.8 LAMS status.....	81
5.9 Riders.....	82

PART 6 CONCLUSIONS	83
PART 7 REFERENCES	84
PART 8 APPENDICES.....	85
8.1 Logistic Regression Modelling details	85
8.2 Correlations.....	85
8.3 Linearity of continuous variables within the logistic relationship	86
8.4 Effect of Registration Year on Injury Crash Risk	86
8.5 Alternative modelling of Redbook types	88
8.6 Frequency of Redbook types by jurisdiction.....	91

FIGURES

Figure 1 Percent of crashed motorcycles matched with matching registration data	18
Figure 2 Injury crashes per 100,000 registered motorcycles (bars) and registered motorcycles (solid line) in NSW and Victoria.....	31
Figure 3 Australian motorcycle injury crashes by severity and jurisdiction (2005 to 2014)	32
Figure 4 Predicted probability of an injury crash for each year, at average engine capacity and power-to-weight ratios for NSW and VIC (alpha=0.05)	33
Figure 5 Predicted probability of a fatal or serious injury crash for each year, at average capacity and power-to-weight ratios for NSW and VIC (alpha=0.05)	34
Figure 6 Crash severity odds ratios for each registration year, relative to the base year of 2005	34
Figure 7 Crash severity odds ratios for each jurisdiction, relative to NSW	35
Figure 8 Distribution of motorcycle age and year of manufacture amongst NSW and VIC registered motorcycles in 2005 and 2014.....	36
Figure 9 Odds of an injury crash for each year of manufacture relative to 1990.....	37
Figure 10 Odds of a fatal or serious injury crash for each year of manufacture relative to 1990.....	38
Figure 11 Odds of a more serious injury crash for each year of manufacture relative to 1990	39
Figure 12 Injury and fatal and serious injury crash rates by motorcycle age and registration year	40
Figure 13 Ten year average injury crash distribution by motorcycle age and rider licence type or engine size	41
Figure 14 Ten year average injury crash rates per 100,000 registrations by motorcycle age and Redbook type	42
Figure 15 Stacked distribution of engine size amongst RVCS matched registration data (2005 to 2014) and Average Injury crash rates per 100,000 registrations by LAMS status and engine capacity	43
Figure 16 Injury and fatal and serious injury crash rates per 100,000 registrations by engine size categories	44
Figure 17 Odds of an injury and of a fatal or serious injury crash for each engine size category relative to the 251-749 cc categories	45
Figure 18 Predicted probability of an injury or fatal and serious injury crash by engine capacity for 2014 and each jurisdiction, at average power-to-weight ratios (alpha=0.05)	46
Figure 19 Predicted probability of a more severe injury crash outcome by engine capacity for metropolitan NSW in 2014 at reference covariate values and average engine power-to-weight ratio (alpha=0.05). Note: Motorcycle engine capacities are typically range 50cc-1600cc.....	47
Figure 20 Stacked Distribution of power-to-weight ratio amongst RVSC matched registration data (2005 to 2014) and the Average Injury crash rates per 100,000 registrations by LAMS status and power-to-weight ratio	47
Figure 21 Injury and fatal and serious injury crash rates per 100,000 registrations by power-to-weight ratio categories (kW/t).....	48
Figure 22 Predicted probability of an injury or fatal and serious injury crash by power-to-weight ratio for 2014 and each jurisdiction, at average engine capacity (alpha=0.05)	49

Figure 23 Predicted probability of more severe injury crash outcome by power-to-weight ratio (PWR) for metropolitan NSW in 2014 at reference covariate values and average engine capacity (alpha=0.05)	49
Figure 24 Injury and Severe Injury crash rates per 10,000 registrations by LAMS status and Redbook type	50
Figure 25 Injury and Severe Injury crash rates per 100,000 registrations by LAMS status	51
Figure 26 RVCS matched registration data (2005 to 2014) by Redbook type, percentage of all and counts per registration year.....	52
Figure 27 Injury crash rates per 100,000 registrations by Redbook type (2005 to 2014)	53
Figure 28 Odds of an injury crash by Redbook type (2005 to 2014).....	54
Figure 29 Odds of a fatal or serious injury crash by Redbook type (2005 to 2014)	54
Figure 30 Odds of a severe injury crash outcome by Redbook type (2005 to 2014)	55
Figure 31 Proportion of crashes by rider attribute categories	57
Figure 32 Proportion of crashes with licence type within a Redbook type by crash injury.....	58
Figure 33 Proportion of crashes with female riders and proportion of crashes of rider age groups within a Redbook type by crash injury category: over 2004-2015	58
Figure 34 Injury Crash rates per 100,000 registrations for rider attributes by crash year	59
Figure 35 Average 10 year injury crash proportions for motorcycle age groups by rider sex and age	60
Figure 36 Average 10-year injury crash rates per 100,000 registrations of same Redbook type by Rider age	61
Figure 37 Average 10-year injury crash rates per 100,000 registrations of Redbook type by Rider sex.....	62
Figure 38 LAMS Ratio of rider age grouped injury crash rates per registration: Approved to Not Approved	62
Figure 39 Odds ratio of a severe injury crash outcome by rider licence type	63
Figure 40 Odds Ratio of a severe injury crash outcome by rider age, sex and helmet wearing status	63
Figure 41 Proportion of injury crashes by crash location	64
Figure 42 Crash rates per 100,000 registrations for crash location by crash year.....	65
Figure 43 10-year average injury crash rates per 100,000 registrations by	66
Figure 44 LAMS Ratio of location grouped injury crash rates per registration: Approved to Not Approved ...	67
Figure 45 Odds ratio of a severe injury crash outcome by crash location	67
Figure 46 Proportion of injury crashes by crash conditions.....	68
Figure 47 Crash rates per 100,000 registrations for crash conditions by crash year.....	69
Figure 48 LAMS Ratio of condition grouped injury crashes rates per registration: Approved to Not Approved	70
Figure 49 Odds ratio of a severe injury crash outcome by crash conditions.....	70
Figure 50 Proportion of injury crashes by crash types	71
Figure 51 Crash rates per 100,000 registrations for crash types by crash year	72
Figure 52 Average 10-year injury crash rates per 100,000 registrations by Redbook type and crash type ...	73

Figure 53 LAMS Ratio of crash type grouped injury crash rates per registration: Approved to Not Approved	73
Figure 54 Odds ratio of a severe injury crash outcome by multi and single vehicle crash types	74
Figure 55 Odds ratio of a severe injury crash outcome by manoeuvre or object hit.....	75
Figure 56 Specific type crash rates per 100,000 registrations (disaggregated) by Redbook type	76
Figure 57 Odds of an injury crash and the odds of a fatal or serious injury crash, for each registration year, 87	
Figure 58 Predicted probability of a severe injury crash outcome for each registration year and jurisdiction, for metropolitan regions, at average capacity and power-to-weight ratios and reference values of other covariates (alpha=0.05, model v)	88
Figure 59 Odds of an injury crash by Redbook type (2005 to 2014) referenced against all other types	89
Figure 60 Odds of a fatal or serious injury crash by Redbook type (2005 to 2014) using referencing against all other types	90
Figure 61 Odds of a more serious injury crash by Redbook type (2005 to 2014) using two different models of referencing	90
Figure 62 RVCS matched registration data (2005 to 2014) by Redbook type and Jurisdiction	91

TABLES

Table 1 Percent match for RVCS data with NSW and VIC registrations (by year)	19
Table 2 Percent contribution to whole injury crash dataset by Jurisdiction	20
Table 3 Percent VIN decoded by Jurisdiction.....	20
Table 4 Percent VIN decoded by crash year for Western Australia	20
Table 5 Comparison of engine capacity in full and reduced (RVCS matched) logistic regression (registration) data sets	21
Table 6 Motorcycle attributes used in registration data logistic regression models	22
Table 7 Motorcycle attributes used in crash data logistic regression models	23
Table 8 Risk Characteristics by Redbook type	30
Table 9 Injury crash Odds ratio reductions associated with engine capacity by type	56
Table 10 Serious and fatal crash odds ratio reductions associated with engine capacity by type	56
Table 11 Goodness of fit statistics for Table 6 Logistic regression models.....	85

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EXECUTIVE SUMMARY

Introduction

Motorcycles have shown the fastest relative growth of all registered motor vehicles in Australia over the last 10 years. The proportion of road fatalities and seriously injured road users that are motorcyclists has also increased in recent years to 19% of all fatalities in 2016. The aim of this project was to characterise current trends in motorcycle related road trauma to guide effective safety interventions such as targeted infrastructure improvements, rider education programs, recommendation of vehicle safety features and licensing initiatives. A unique aspect of this project was the inclusion of more detailed motorcycle characteristic information, including LAMS status, Redbook motorcycle type, and power to weight ratio, in the analysis of injury crash risk. This was achieved by matching vehicle specification data to both registration and police reported crash data.

Data and Methods

Police reported crash data for South Australia (SA), Western Australia (WA), Queensland (QLD), Victoria (VIC) and New South Wales (NSW), and annual snapshots of registration data for Victoria and New South Wales, for the years 2005 to 2014, were matched with motorcycle type based on Redbook categories and other vehicle characteristics using a process of Vehicle Identification Number decoding based on motorcycle attribute data from the Road Vehicle Certification Scheme (RVCS). The combined dataset for the 10-year period was used to summarise trends by motorcycle type and attributes for injury crashes, registered vehicles and raw crash rates per registered vehicle. Logistic regression was used to estimate the odds of a severe injury crash outcome in the event of a crash. Crashes were matched to vehicle registration data so that the odds of a fatal and serious injury crash or the odds of an injury crash per registered vehicle year could also be estimated.

Evaluation of LAMS status, engine capacity, motorcycle year of manufacture, power-to-weight ratio and motorcycle type as predictors of injury or fatal and serious injury crashes were made through logistic regression modelling. Correlations of these covariates were examined; power-to-weight ratio (PWR) and engine capacity were not strongly correlated. This meant that the combined predictive power of both power-to-weight ratio and engine capacity could be compared with the predictive power of LAMS status or year of manufacture.

Key Results

Overall injury crash outcomes

1. Injury crash outcomes were worse for motorcyclists than drivers of other vehicle types, and this difference increased over the 10-year period.
 - Adjusted for motorcycle attributes and year, the crash risk was approximately 1% per annum for an injury crash and 0.5% per annum for a fatal or serious injury crash. Just under half of reported motorcycle injury crashes resulted in fatal and serious injuries. In contrast, about one quarter of passenger vehicles from Police reported injury crashes involved fatal and serious injury crashes.
 - The proportion of severe injury¹ outcomes increased for motorcycle injury crashes over the 10-year period. In raw terms, the ratio of fatal and serious to minor injury crashes increased from 0.8 to 1.0. When adjusted for crash, rider and vehicle attributes, the odds of a severe outcome for an injury crash increased from 2010 and peaked in 2013 at 1.83 times the 2005 odds ratio.
2. Injury crash outcomes differed significantly between state jurisdictions:
 - The number of motorcycle injury crashes increased in NSW over the ten years, whereas for other jurisdictions this was not the case. Over the period, injury crashes in WA, VIC and SA were fairly stable and in QLD they declined. When expressed relative to registration numbers (which increased over 10 years), there were overall decreasing crash rates for NSW and VIC.
 - The odds of a more severe injury crash outcome were lower for SA and higher for QLD and VIC when compared to NSW.
3. There were more motorcycle injury crashes than population proportions would predict in remote and rural areas but this trend decreased over time.
 - 35% of injury crashes (and 40% of serious injury crashes) were in rural or remote regions and just under 30% (and just over 30% for fatal and serious injury crashes) occurred in speed zones of 80 km/hr or more.
 - Over the 10-year period the proportion of injury crashes in 50 km/h and lower speed zones increased.

¹ Severe injury= fatal injuries and injuries requiring hospital admission.

Serious injury= injury requiring hospital admission.

4. Injury crash severity was higher in more remote regions and in higher speed zones.
 - The odds of a more severe injury crash were 48% higher if the crash region was remote (relative to rural).
 - The odds of a more severe injury crash were 49% higher if speed zone was 80 km/hr and over (relative to 60 and 70 zones).

Crash types, speed zones and road conditions

5. Serious injury outcomes for motorcyclists were less likely in lower speed, and intersection crashes².
 - The odds of a more severe injury crash outcome were lower by 12% if the crash was at an intersection (relative to not at an intersection). Intersection crashes represented about 40% of all injury and serious and fatal injury crashes.
 - The odds of a more severe injury outcome were lower by 11% ($p<0.0001$) if the speed zone was 50 km/h and under (relative to 60 and 70 zones).
6. Multi-vehicle motorcycle injury crashes had more serious outcomes (relative to single vehicle) and over 50% of motorcycle injury crashes were multi-vehicle. This finding suggests that countermeasures directed at reducing multi-vehicle crashes should be a priority regardless of the location. For example, it is not enough to target intersection crashes; it is important to target specific crash types, including head-on and fail-to-give way crashes.
 - The odds of a more severe injury crash outcome were higher relative to single vehicle on-carriageway loss-of-control motorcycle injury crash by:
 - 3.36 times ($p<0.0001$) for a head-on crash;
 - 1.95 times ($p<0.0001$) for a turn-in-front-of crash;
 - 1.70 times ($p=0.005$) for a cross-in-front-of crash;
 - 29% ($p=0.0003$) for other types of multi-vehicle crashes;
 - 18% ($p<0.0001$) for a rear-end crash;
 - 8% ($p<0.0001$) for a sideswipe/lane change crash.
 - Turn-in front of crashes made up about 20%, and rear-end about 10% of motorcycle injury, and fatal and serious injury crashes.
7. The odds of a more severe injury crash outcome³ in single vehicle crashes were higher for motorcycles leaving the carriageway when compared to those staying on the carriageway. The odds of a more severe single vehicle injury crash were:
 - 27% lower ($p<0.0001$) if the crash was on the carriageway and not involving loss of control (compare to single vehicle run-off road).
 - 34% lower ($p<0.0001$) if the crash was on the carriageway and involving loss of control (compared to single vehicle run-off road).
8. The odds of a severe injury crash outcome were higher by:
 - 68% ($p=0.0003$) if cornering and multi-motor vehicle (relative to not cornering);
 - 44% ($p=0.0002$) if a pedestrian was involved (relative to not);
 - 16% ($p<0.0001$) if an object or animal was hit (relative to not);
 - 6% ($p=0.0014$) if cornering and single-motor vehicle (relative to not cornering);
 - Cornering crashes made up about 20% of motorcycle injury and fatal and serious injury crashes.
9. The proportion of motorcycle injury crashes on wet roads and at night increased over the 10- year period.
 - The odds of a more severe injury crash outcome were 32% ($p<0.0001$) higher in dark conditions (relative to light) and higher by 12% ($p=0.0048$) in dawn/dusk conditions (relative to light).
 - The odds of a more severe injury crash outcome were 19% ($p<0.0001$) lower in wet/foggy or snowy weather (relative to dry).

Riders

10. Injury crashes increased for older riders, and their outcomes were relatively poorer.

²73% of motorcycle crashes in speed zones of 50 km/hr and under and 77% of intersection motorcycle crashes are in metropolitan regions.

³48% of single vehicle motorcycle crashes were in rural or remote regions and 59% of rural and remote motorcycle crashes were single vehicle crashes.

- Raw injury crash rates for riders aged 60 years and over doubled over the ten years.
 - The proportion of riders aged 60 years and older involved in injury crashes doubled (from 3% to 7%) over the 10-year period.
 - The odds of a severe injury crash outcome increased with rider age and were higher by 39% ($p<0.0001$) if the rider was aged 60 years and over (relative to riders aged 25-59).
 - The proportion of older riders involved in an injury crash increased to a greater extent for those involving older motorcycles.
11. Female rider injury crash counts increased over the 10-year period, and their rate of injury crashes (relative to registrations) decreased less than for male riders.
- On average, 10% of crashed riders were female.
 - Crash counts increased by 2.6% (comparing 2005 and 2014) for female riders and decreased by 15% for male riders; expressed as a crash rate per 100,000 registrations (not disaggregated by sex,) this translated to a 17% decrease in female rider crash rate and a 37% decrease in male rider crash rate over time.
 - Female riders trended toward younger vehicles and males toward older vehicles.
 - No significant gender difference was found for crash severity.
12. Unlicensed riders increased in proportion over the 10 year period and had poor relative risk and outcomes.
- The proportion of unlicensed rider crashes increased and unlicensed riders were more likely to have a severe injury crash outcome by 25% ($p=0.02$) when compared to fully licenced riders.
 - One in every five injury crashed riders were not on their full licence.
13. Learner riders were more likely to crash on older motorcycles and have poorer relative injury outcomes.
- Just under a quarter of injury crashed riders were aged under 25 and about 15% of injury crashed riders were on a probationary or learner licence.
 - The odds of a more severe injury crash outcome were greater by 12% ($p=0.035$) if the rider was a learner rider (relative to Full licence rider).
 - The greatest proportions of learner riders (within motorcycle age groups) were found for crashed motorcycles older than 16 years.
14. In contrast to the general rider population, raw injury crash rates increased for probationary riders over the 10-year period.
15. Helmet wearing was associated with less serious injury outcomes.
- The odds ratio of a severe injury crash outcome were 72% higher if the rider was not wearing a helmet by ($p<0.0001$), however, only 3% of crashed riders were identified as not wearing a helmet and this decreased from 5% to 2% over the ten year period.

[Motorcycle types, engine capacity and power-to-weight ratio \(PWR\)](#)

16. The three most popular motorcycle types, Off-road, Cruisers and Sport, were also ranked as the three with the highest relative risk of more severe injury crash outcomes. Sport motorcycles were also rated among the highest for injury crash risk and for fatal and serious injury crash risk.
17. Touring type motorcycles were ranked as the lowest injury risk in this study, despite having one of the lowest proportions of learner approved (LAMS) motorcycles.
18. Large engine capacity motorcycles occupied a large proportion of the motorcycle-registered fleet and some associations were found between engine capacity and serious injury outcomes.
- Registrations in 750 cc engine capacity and above motorcycles increased (slightly) over 10 years relative to those of 250cc capacity and under.
 - On average over one third of registrations were for engine capacities of 750cc or more and about two thirds were for more than 250cc.
 - Increased odds of an injury crash were associated with increases in engine capacity both for Road and Off-Road motorcycle types.
 - Increased odds of a more severe injury crash outcome were associated with increases in engine capacity regardless of motorcycle type.

19. High power-to-weight ratio (PWR) motorcycles occupied a significant and increasing proportion of the motorcycle-registered fleet, which is a concern due to observed associations between PWR and severe injury outcomes.
 - More than thirty percent of registered motorcycles had a power-to-weight ratio (PWR) exceeding the LAMS limit of 150 kW/t.
 - The proportion of 350 kW/t registrations almost doubled over the 10-year period.
 - The injury and fatal and serious injury crash risks and the odds of a severe injury crash outcome were all found to be associated with increasing PWR, although the estimated effects on crash severity were small within the normal PWR ranges.
20. In the definition of LAMS status, the association between engine capacity and injury crash risk varied significantly between different motorcycle types.
 - Engine capacity was found to be associated with increases to injury crash risk for some motorcycle types (e.g. Naked, Sport, Off-road other) yet associated with decreases for others (e.g. Off-road Enduro). See Table 9 and Table 10 for detail.
 - However, LAMS status was also found to be confounded with rider experience, so it is possible that the motorcycle type effect was produced by types that were most popular amongst the inexperienced. Off-road motorcycle injury crashes are also more likely to be under-reported.
21. While older motorcycles were not a large presence in the registered fleet, their prevalence was high amongst crashes involving unlicensed and novice riders.
 - Motorcycles aged 16 years and over made up about 16% of registrations.
 - The injury crash rates for this group of older motorcycles remained lower than that of the other age groups over the ten years.
 - This motorcycle age group was made up of the greatest proportion of unlicensed and learner riders and learner rider injury crashes and this proportion increased over the 10-year period.
 - The odds on an injury crash decreased with each (more recent) year of manufacture after 2007, suggesting safety benefit for newer motorcycles.

Suggested countermeasures

Road Users

1. Strategies to increase conspicuity of motorcyclists to other road users. Low conspicuity is associated with the risk of collision (Oxley, 2011). Countermeasures to improve rider conspicuity so that multi-vehicle motorcycle injury crashes are mitigated or reduced in severity include:
 - a. The use of daytime running lights (DRL) and modulating headlights are likely to have benefits. Road safety regulations in some states of Australia (including NSW and Victoria) permit the use of modulating headlights on motorcycles that meet specific requirements (e.g. Road Safety Regulations 2009 S.R. No. 118/2009). Further study is needed to establish efficacy with motorcycles on Australian roads.
 - b. Promotion of the use of high visibility clothing is recommended to increase rider physical conspicuity and improve outcomes in low ambient light, glare and poor weather as well as in multi-vehicle crashes generally. Wells et al (2004) showed that crash risk was higher for riders using darker helmets and that riders wearing any reflective or fluorescent clothing had a 37% lower risk of crash related injury than other riders. Scope for improvement was established in 2016 (Allen et al.) in findings that over half of passing riders were wearing dark colours with no fluorescent or reflective surfaces.
 - c. Future evaluation of high visibility clothing and effects on injury crashes. Some jurisdictions (including Victoria) already make the use of high visibility clothing a requirement for learner riders, making a future evaluation of this policy using crash data possible. While the balance of current evidence suggests positive benefits, preliminary results from the current MUARC case-control study did not show reduced injury crash risk for those wearing high visibility clothing.
2. Licence refresher training for older riders, to pre-empt further increases in serious injury and fatalities for this group due to changes related to the ageing rider population and their greater vulnerability. The Victorian older road user study (2006-2015) found that older riders experienced growth in licensing of almost 300% and within the licensed, the learner permits doubled over the period 2006 to 2015. Older motorcyclists were also more likely to ride on open roads, which at higher speeds makes them more vulnerable. It also found them more likely to have injuries when stopped or maneuvering. While a reduced crash risk has been associated with more years of on-road riding experience in Victoria (Allen et al. 2017), preliminary data from the MUARC case-control study suggests that riders returning from an extended break in riding (>12mths) are at increased risk of an injury crash. Thus, skill-based training or education targeted for older returning riders may improve their crash risk and injury outcomes.
3. Promote the use of high quality protective clothing. This may include education strategies or introducing national

standards for motorcycle protective clothing. A star rated system for motorcycle clothing is currently being developed in Australia to help riders make informed choices.

4. Police continue with licence checking strategies to reduce the increasing prevalence of injury crashes involving unlicensed riders and improve compliance to licensing requirements. Automatic Number Plate Recognition might have particular benefits when applied to the motorcycle population.
5. Road user-based safety strategies should also accommodate and target female riders, given the growing percentage of female riders and their increased representation in motorcycle injury crashes.

Speed related

6. Strategies to reduce vehicle travel and impact speeds. Motorcyclists are vulnerable to impacts with other vehicles, the ground and road infrastructure (ETSC, 2008). Lower travel speeds decrease the severities of impact injuries (ACEM 2004) and give riders and other road users more time to react to a situation. In Victoria, inappropriate rider speed was found to be associated with other forms of rider error for multi-vehicle crashes (Allen et al, 2017). Thus countermeasures to address the high proportion of injury crashes with severe outcomes generally include:
 - a. Identify appropriate advisory speeds and speed limits in high motorcycle exposure and crash risk areas, especially at intersection and corner approaches, and employ speed lowering strategies where needed (such as reduced limits or increased enforcement).
 - b. Police continue with, or increase frequency of, speed enforcement for all vehicle types, including camera enforcement of motorcycles from the rear, and covers approaches to intersections (see above).
 - c. Intelligent Speed Adaption as a penalty for recidivist speeders (Oxley 2011, NSW Centre for Road Safety 2010) and for general use to help road users maintain speeds within limits may be useful. This requires further evaluation.

Road infrastructure

7. Improvement of road infrastructure for motorcyclists in high-speed zones, on open roads in rural locations, and at intersections (40% of injury crashes), including addressing turn-in-front-of (20% of injury crashes) injury crashes. The road environment, (mostly in the form of design and maintenance issues), has been identified as a secondary contributor to motorcycle crashes in 78% of cases and has been identified as a primary contributor in a higher proportion of single vehicle than multi-vehicle crashes (Allen et al. 2017). Allen et al. (2017) identified common road design issues were poor intersection design, poorly signed roads, reduced road widths and fixed obstructions. Maintenance issues identified as most common included: loose material on the road and a poor road surface condition. Infrastructure has been evaluated by MUARC for VicRoads and the TAC generally, but it may be necessary to design an evaluation specific to motorcycles to find the most cost-effective infrastructure improvements. In the recent Safer Road Infrastructure Project (SRIP) evaluation (Budd & Newstead 2016), significant rider injury reductions (bracketed) were associated with the following treatments:
 - shoulder sealing (29%);
 - shoulder sealing and hazard removal (58%).

In the recent Safer Road Infrastructure Project (SRIP) evaluation, significant fatal and serious rider injury reductions (bracketed) were associated with the following treatments:

- intersections in metropolitan areas (61%)
- rural road segment (52%)
- shoulder sealing (41%)
- traffic signal treatments (75%)
- new traffic signal installations (91%)
- right turn modification (63%)
- installation of fully controlled right turn and extension/installation of right turn lane (80%)

Suggestions for road infrastructure countermeasures are:

- a. Suitable barrier instalment to reduce run-off road injuries in targeted locations and bends (Oxley, 2011).
- b. Skid resistant surfaces and improved road and shoulder surfaces generally to help motorcyclist maintain control given the inherent instability of a two-wheeled vehicle.

- c. Dedicated turning lanes to reduce turn-in-front-of crashes.
- d. Signs and shrubs that do not obscure motorcycles; visibility must be optimal (Doğan et al, 2004), especially in glare conditions.
- e. Reduced speed limits on approach to complex intersections (Oxley, 2011).
- f. Fully controlled signals for turns, to reduce turn-in-front-of crashes.

Vehicles

- 8. Promote or support motorcycle safety technologies that mitigate high-speed run-off road and cornering crashes as well as intersection crashes. These may need further evaluation by simulation or by real-world crash analyses as they penetrate the fleet.
 - a. Anti-lock braking systems (ABS) are the most recent well-developed motorcycle technology with strong evidence of safety benefits (Rizzi et al, 2009 and 2015). The inherent instability of motorcycles is exacerbated when braking (Oxley, 2011, Ouellet, 2006). Ineffective braking has been identified as a key contributor to these crash types (Hawthorn et al. 1997, Allen et al. 2017). It is noted the braking technologies need to work with other impact speed lowering strategies (discussed in point 2) including inappropriate speed zones and travel speeds for both multi- and single vehicle crashes. ABS has recently been mandated in Europe for all new motorcycles with greater than 125cc engine capacity. A similar strategy is likely for Australia from 2019. Other strategies to increase uptake of ABS into the Australian fleet are recommended.
 - b. Motorcycle Autonomous Emergency Braking (MAEB) is similar to the equivalent technology for passenger cars (AEB). This is currently being developed and evaluated with positive preliminary findings (Savino 2013). Further support, development and evaluations are required before MAEB reaches the market.
 - c. Collision and hazard warning systems. Collision warning systems (CWS) can warn of impending collisions and departures from lanes. An Advanced Rider Assistance System (ARAS) provides warnings to the rider if their approach speed to a hazard is inappropriate, including curves and intersections. While these systems offer potential based on the known contribution of human error (by other road users or riders) to serious injury motorcycle crashes (Allen et. al, 2017), more work is needed to determine their effectiveness in motorcycles and their acceptance by riders (Oxley 2011, SAFERIDER 2010, Huth & Gelau 2013).
 - d. Airbags may be associated with an overall benefit in reducing injury severity (Ulleberg, 2003). Further research and development is also required.
- 9. Promote current and future safety technologies for other vehicle types that are likely to reduce prevalence of crashes with motorcycles. Current technologies (e.g. AEB, ESC) are likely to reduce collisions with motorcyclists. Future technologies that reduce fail-to-give-way errors by the other road user would offer significant potential for reducing motorcycle injury crashes.
- 10. Further research on injury crash risks associated with engine size, rider experience and motorcycle type. This is needed to validate the observed relationships of crash risks varying positively and negatively with engine size depending on the type of motorcycle (Redbook). If valid, then there is opportunity to reduce injury outcomes of novice riders by re-assessment of the LAMS to allow for engine capacities relevant to the motorcycle type.

PART 1 INTRODUCTION

Motorcycles have shown the fastest relative growth of all registered motor vehicle types in Australia over the past 10 years. Exposure has increased significantly, with motorcycle registrations increasing by approximately 5% per year and estimated kilometres travelled increasing by 4 per cent per year (BITRE, 2017). While the number of motorcycle fatalities today is similar to ten years ago, the proportion of all road fatalities that are motorcyclists has increased over the same period from 13% to 18% (based on 5-year averages, ABS, 2017). For every motorcyclist killed, 35 more are hospitalised due to traffic related crashes. Motorcyclists accounted for just under 1 in 4 cases of traffic-hospitalised injury in 2013, compared to 1 in 2 for passenger cars (BITRE, 2017). Therefore, while national trends in motorcyclist fatality rates per registered vehicle have improved, the absence of a reduction in absolute number of fatalities and increased proportion of all road-related serious injuries highlights a need to understand better the characteristics and trends of these crashes, so that effective countermeasures can be developed.

The aim of the project was therefore to characterise current and future motorcycle related road trauma to guide effective safety countermeasures such as targeted infrastructure improvements, rider education programs, recommendation of safety features and licencing initiatives. In particular, the association of crash risk and motorcycles currently approved by the Learner Approved Motorcycle Scheme (LAMS) was examined to establish its relevance to rider safety. Australian Police reported motorcycle injury crash data as well as vehicle characteristics from registration data were used to examine trends and crash risks for motorcycle crashes over a 10-year period (2005-2014). Odds ratios adjusted for jurisdictions and registration years were also examined.

PART 2 DATA

2.1 RVCS and Redbook data

Data for all motorcycles certified by the (Australian) Road Vehicle Certification Scheme (RVCS) over the period 1985 to 2015 were compiled by Monash University Accident Research Centre (MUARC) from the RVCS website⁴. These data were merged with motorcycle classification data purchased from Redbook⁵. The variables within this data were mostly complete (not missing) for motorcycle VIN (Vehicle Identification Number), body type (e.g. "Solo"), engine capacity, power, tare and Redbook type. Other variables such as engine type (e.g. "2ST"), ADR class and intake type were up to 30% missing, so were not used in this analysis.

The RVCS data were used to produce a list of unique 12 digit VINs that could be translated into make, model and variant and associated other variables. Sometimes more than one variant, body type, engine capacity, power and tare were associated with a unique 12 digit VIN. In these cases, the average, minimum and maximum values and multiple Redbook categories were associated with the VIN. These VINs were used to decode crash and registration data into makes and models and to associate other Redbook and RVCS variables. As the years of crash and registration data surpassed the upper year of RVCS data, decoded data is richest in the years just prior to the upper limits (*Table 1*).

In the charts, tables and modelling which follow, cases with more than one Redbook type were counted in every category that they appeared within unless otherwise stated.

In addition to the RVCS variables, the LAMS (Learner Approved Motorcycle Scheme) status as approved or not approved was added as a variable according to the criteria defined on government web pages⁶.

2.2 Registration data

Motorcycle registrations over the period 2004 to 2016 were extracted from annual mid-year snapshots of registration data from New South Wales (NSW) and Victoria (VIC) provided to MUARC for generating the Used Car Safety Ratings⁷. A set of unique motorcycles (with information on years registered) was prepared for each jurisdiction. These two registration sets were decoded and matched with RVCS and Redbook data. By using registration plate, VIN and year of manufacture (YOM), these motorcycles could be matched with the respective crash data, enabling the associated RVCS and Redbook data to also be matched to the crash data. Full VIN meant that YOM was not really needed for the Victorian crash data matching, however, even with YOM, a 12 digit VIN and registration plate was not always unique for the NSW registration data. When this occurred (NSW), the registration year was compared with the crash year to see which non-unique motorcycle was the best match. Match success is presented in Figure 1.

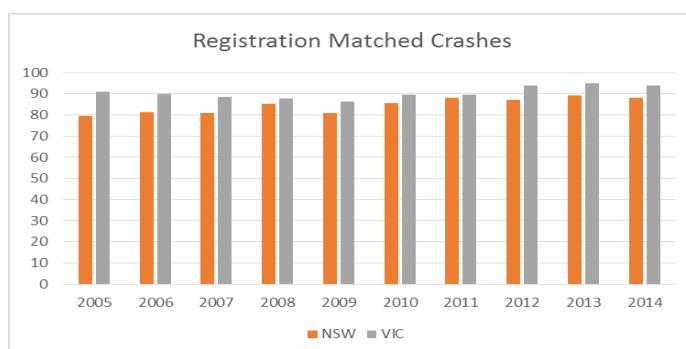


Figure 1 Percent of crashed motorcycles matched with matching registration data

⁴ http://rvcs.infrastructure.gov.au/pls/wwws/pubrvcs.Notify_Search

⁵ This was done by J.Thompson for other projects.

⁶ <https://www.sa.gov.au/topics/driving-and-transport/drivers-and-licences/motorcycle-licences/learner-approved-motorcycles>

http://www.transport.tas.gov.au/_data/assets/pdf_file/0009/108477/MR42_10_14_fact_sheet_LAMS_approved_motorcycles.pdf

http://www.transport.wa.gov.au/mediaFiles/licensing/LBU_DL_B_LAMS_Fact_Sheet.pdf

<http://www.rms.nsw.gov.au/documents/roads/licence/approved-motorcycles-for-novice-riders.pdf>

<https://www.qld.gov.au/transport/licensing/motorcycles/learner-approved>

www.vicroads.vic.gov.au/licences/licence-and-permit-types/motorcycle-licence-and-learner-permit/approved-motorcycles-for-novice-riders

⁷ <http://howsafeisyourcar.com.au/Rating-Process/What-is-UCSR/>

Continuing from this matching, information on crashed motorcycles (year of crash, severity of crash, number of crashes per year) was matched to the registration data, so that for each registration year, a motorcycle could be classed as crashed or not for the purposes of logistic regression analysis.

Over the period, there were 668,075 unique NSW and 580,349 unique Victorian registered motorcycles, which translated respectively to 447,987 and 379,168 cases (67% and 65%) with associated RVCS data. *Table 1* depicts the proportions matched by year.

TABLE 1 PERCENT MATCH FOR RVCS DATA WITH NSW AND VIC REGISTRATIONS (BY YEAR)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
% of all with RVCS match	61	58	61	63	73	74	74	75	75	74

In addition to the RVCS source, engine size was a variable within the VIC registrations data. Where VIN decoding produced a make and model, and where RVCS data matching came up with a missing engine size, the engine size from VIC registrations information could be merged onto the same (RVCS) makes, models and VINs for NSW registrations.

A number of limitations to the registration data should be noted.

Motorcycles were identified within NSW registration data by a motorcycle indicator variable, and were easily distinguished from passenger, plant and heavy vehicles. Motorcycles were identifiable with and without sidecars; however, two wheeled vehicles could not be separated from three and four wheeled non-passenger vehicles. Motorcycles were identified in a similar manner within the Victorian registrations, however, the number of wheels was provided and three and four wheeled vehicles were excluded.

In addition, interrogation revealed that NSW motorcycle registrations (with no missing VIN) provided over 2007 to 2012 numbered almost double the corresponding motorcycle registrations reported for NSW in the Australian Bureau of Statistics motor vehicle censuses. In this period, off-road motorcycle registrations were more than doubled, however sports, road and cruiser motorcycles were also observed to increase by at least 40%. To address this limitation, the rate of change in ABS recorded registrations were used to model the registration count for 2017 to 2012. This '*ABS-adjusted*' count was used when analysing raw crash rates per registration. All charts using the adjusted counts are labelled as such. When presenting raw crash rates per disaggregated registration data (, for example by engine size, year of manufacture or Redbook type), data as provided were used, as it was not possible to adjust by registration attributes. This will have the effect of reducing crash rates, over all years, or by year for 2017 to 2012, where the registration count for the attribute is over represented. Crash risk measured from crashes matched to registration data will be less susceptible to this bias because the registration year was included as a regression variable, so estimates were adjusted for differences related to the year.

The use of registrations as a measure of exposure for injury crash risk estimates is also limited. This measure of exposure does not account for kilometres travelled and thus over-estimates the risk for vehicles types that are garaged for most days of the year (e.g. tourers), and under-estimates the risk for vehicles that spend most days on the road. In addition, injury crashes involving recreational off-road motorcycling on unsealed roads (either on or off public roads) is likely to be under-represented, due to the remoteness of crash location. This limitation is further discussed in Section 5.

2.3 Crash data

An analysis dataset was compiled from Police reported crash data from five Australian Jurisdictions, (Queensland (QLD), NSW, VIC, South Australia (SA), and Western Australia (WA)) over the crash years 2005 to 2014 inclusive. This compilation comprised 83,256 motorcycles involved in injury crashes (with at least one person injured in the crash). More than half of the potential cases were from New South Wales and Victorian combined data (*Table 2*). Excluding Western Australian data, about 80% of these motorcycles had a recorded VIN to decode, so that in excess of 60% of motorcycles could be associated with motorcycle characteristics data obtained via RVCS (*Table 3*). For Western Australia, VINs were only available for 21% of the data, and these were available only for specific crash years (

Table 4).

The VINs from both registration and crash data were decoded. The reasons generally for failure of VIN decoding include: no VIN, unusual VIN (e.g. 00000N), incorrectly recorded VIN and VIN is not within the scope of the decoding syntax. Minority makes, tricycles, quads and most vehicles with year of manufacture prior to 1990 are beyond the scope of the VIN decoder.

TABLE 2 PERCENT CONTRIBUTION TO WHOLE INJURY CRASH DATASET BY JURISDICTION

	Frequency	Percent
NSW	25,482	31
VIC	20,473	25
QLD	14,127	17
WA	17,594	21
SA	5,580	7
Total	83,256	100

TABLE 3 PERCENT VIN DECODED BY JURISDICTION

	% with VIN	%decoded	% with RVCS data
NSW	79	73	59
VIC	89	84	68
QLD	81	75	60
WA	23	21	18
SA	86	80	65
Total	70	65	53

TABLE 4 PERCENT VIN DECODED BY CRASH YEAR FOR WESTERN AUSTRALIA

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
% with VIN decode	18	38	33	37	21	22	26	0	15	0

Injury crashes were further disaggregated into the categories: Fatal, Serious and Minor. *Serious injury crashes* involved a person being hospitalised. *Minor injury crashes* involved no hospitalisations nor fatalities. The combination of fatal and serious injury crashes combined is often given the title, *severe injury crashes*.

PART 3 METHODOLOGY

Data were analysed by two methods. The first method, involved basic aggregations to describe trends in the combined registration and injury crash data. The second method involved logistic regression analysis for estimations of relative crash and injury risk.

For the chart presentations, injury crash data were aggregated across crash year and other variables, regardless of the unique-ness of a motorcycle. If a motorcycle crashed twice in a year, it was counted twice as a crashed motorcycle. In addition, for crashed motorcycle basic aggregates, motorcycles were not excluded if registration data could not be matched. Motorcycles within the registration data were always unique within a registration year. Basic motorcycle registration aggregates were created without excluding specific years of manufacture, however in order to establish the uniqueness of a motorcycle, a VIN needed to be present. When presented data were disaggregated by RVCS variables, aggregates obviously excluded motorcycle cases that could not be matched with RVCS data. Consequently, raw crash risks presented from the basic aggregates were merely raw rates of injury crashes per registrations and were inclusive of all available years of manufacture.

The dataset prepared for the logistic regression analysis needed only an indicator that an injury crash occurred for the motorcycle within the registration year. Multiple crashes per year were not factored into the logistic regression analyses. When logistic regression was undertaken to estimate crash risks per registered motorcycle, only crash data that matched to registration data could be included. Logistic regressions were modelled with and without RVCS variables. When modelling without RVCS variables, cases which did not match with RVCS data could be included. In order to make this *full* set more comparable to the *reduced* set with fully RVCS matched cases, motorcycles with a year of manufacture under 1990 (, representing 10% of registrations in a year with a recorded VIN) were excluded. Obviously, the *reduced* set excluded cases which did not match to RVCS data, however, the *reduced* set also excluded cases with missing tare weight, engine power and engine capacity. The *full* and *reduced* datasets were found to have very similar annual distributions of many variables, including motorcycle age, jurisdiction and LAMS status. In addition, there were similar distributions of injury and fatal/serious injury annual crash rates. The RVCS matched data (*reduced*) however, showed a slight bias towards motorcycles with smaller engine capacities (Table 5).

TABLE 5 COMPARISON OF ENGINE CAPACITY IN FULL AND REDUCED (RVCS MATCHED) LOGISTIC REGRESSION (REGISTRATION) DATA SETS

	Cases ⁸	% of non-missing				
		Up to 60cc	60 to 250cc	251-749cc	750+cc	(missing)
Full	2,449,902	1.2	32.6	30.4	35.8	(2.7)
Reduced: (RVCS matched and no missing)	1,917,358	1.4	33.7	30.4	34.5	

Of the RVCS matched data with missing tare, power, type or engine capacity (13,266 cases), 96.4% were 1137cc Sport type cycles and 97.7% were NOT learner approved motorcycles and the crash rates were higher than the set without missing values: for fatal and serious crash rates, 36% higher, and for injury crash rates, 20% higher.

Two broad logistic models were employed; one to estimate the contribution of various factors on the odds of an injury crash, and the second to estimate the contribution of various factors to the odds of a severe injury crash outcome given that an injury crash had already occurred. The crash (and RVCS) matched registration dataset was used to model the odds of an injury crash and the odds of a fatal and serious injury crash. These regression models could be adjusted for variables found within RVCS and registration data, such as: registration year, jurisdiction and motorcycle attributes (year of manufacture, engine size, tare weight, power and Redbook type). (RVCS matched) crash data were used to model the odds of a severe injury crash outcome given an injury crash, and, in addition to registration year, jurisdiction and motorcycle attributes, covariate adjustment by crash attributes could be made in these models. Crash covariates are listed in Section 2.

Both of these broad types of logistic regression models were performed on *full* and *reduced* data sets: *full* being all unique motorcycle cases for each year analysed with the restriction of a YOM of 1990 and greater; and *reduced* being a further reduced dataset restricted to only RVCS matched data and no missing values for tare, power or size. Where appropriate *reduced* datasets also excluded cases with a missing Redbook type.

⁸A case here is a unique vehicle-year. Data is in long form with respect to year of registration.

In all logistic analyses, jurisdiction and the registration year were modelled as categorical covariates. This was done so that jurisdictional differences in conditions and data collection, and general changes over time could be taken into account; for example: population increases, traffic volume changes and changes to road infrastructure.

For the *full* datasets, motorcycle attributes were modelled using only YOM and a categorised engine size. For the *reduced* dataset modelling, LAMS status, power-to-weight ratio, engine capacity (in continuous form) and Redbook type were used to represent the motorcycle attributes. *Table 6* and *Table 7* summarise the motorcycle attribute modelling used in the logistic regressions. In addition, the interaction of engine capacity and Redbook type was examined within the context of model (iv) in *Table 6* and model (v) in *Table 7*.

Redbook type was modelled two ways, one with a variable for each Redbook type having a binary (1/0) value and one with a single multi-value categorical variable (which the logistic regression modelled as indicators referenced to a chosen category). The former is useful because it allows a model to be counted in more than one Redbook category⁹.

Likelihood ratio tests, Akaike Information Criterion (AIC) and Schwartz Criterion (SC) goodness of fit statistics were used to compare models and determine the motorcycle attributes which made better predictors of crash risk or crash severity. Details on this process may be found in Appendix 6. The most successful motorcycle attribute predictors were found to be the combination of Redbook type, engine capacity (continuous) and power-to-weight-ratio (continuous).

Engine power and motorcycle tare weight were combined into a single variable 'power-to-weight ratio' (PWR) measured in Kilo Watts per tonne (kW/t). This was done to minimise the collinearity produced by the correlation between power and engine capacity, and between tare weight and engine capacity. Descriptions of the calculation of this variable (as defined by the LAMS) and details of correlated relationships may be found in Appendix 8.2. This variable was used in the definition of a learner-approved motorcycle and thus was an important motorcycle attribute descriptor within this modelling process.

TABLE 6 MOTORCYCLE ATTRIBUTES USED IN REGISTRATION DATA LOGISTIC REGRESSION MODELS

Cases		Response variable	Motorcycle attribute variables (categorical)	Motorcycle attribute variables (continuous)
FULL 2,449,902	i	Injury Crash	YOM, Engine Size (2.7% missing as a category)	
		Fatal or Serious Injury Crash	YOM Engine Size (2.7% missing) ¹⁰	
REDUCED 1,917,358 ¹¹	ii	Injury Crash		Square root of Engine capacity (cc) Power-to-weight Ratio
		Fatal or Serious Injury Crash		Engine capacity (cc) Power-to-weight Ratio
REDUCED 1,916,762 ¹²	iii	Injury Crash	LAMS Status	
		Fatal or Serious Injury Crash	LAMS Status	
	iv	Injury Crash	REDBOOK type	Square root of Engine capacity (cc) Power-to-weight Ratio
		Fatal or Serious Injury Crash	REDBOOK type	Engine capacity (cc) Power-to-weight Ratio

⁹8.6 % of cases in the logistic file had more than 1 Redbook type. For 99% of these it was 2 types. 8.4% of crashes had more than 1 Redbook type; for 99% of these it was 2 types.

¹⁰ Quasi separation of points when Year of manufacture included in model.

¹¹1,930,624 with RVCS data, then 0.7% with no missing values.

¹²With no missing Redbook types.

TABLE 7 MOTORCYCLE ATTRIBUTES USED IN CRASH DATA LOGISTIC REGRESSION MODELS

Response variable is crash severity

Cases	Motorcycle attribute variables		Other Categorical covariates
	(categorical)	(continuous)	
63,458	i	YOM ¹³ ,	As per Section 3.1
42,608 (excludes missing values)	ii	Engine capacity (cc)	Power-to-weight Ratio As per Section 3.1
	iii	LAMS Status	As per Section 3.1
	iv	Redbook types	As per Section 3.1
	v	Redbook types	Engine capacity (cc) Power-to-weight Ratio As per Section 3.1
	vi	LAMS Status	As per Section 3.1
		Redbook types	As per Section 3.1

Both the PWR and engine capacity were modelled in continuous forms. Continuous variables must have a linear relationship within the modelled relationship of the log of the odds ratio. Sometimes this means that a transformation is needed. The process of choosing the correct transformation and the validity of the transformed and untransformed versions of these variables used within the models above is discussed in Appendix 8.3.

3.1 Crash covariates used in crash severity analyses

Reference value is bold

Jurisdiction	QLD, NSW , VIC, SA or WA
Crash year	2005 , 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, or 2014
Location	Metropolitan, Rural or Remote
Speed Zone	≤50 km/hr, 61-79 km/hr , ≥80 km/hr or missing
Intersection Location	Yes or No
Curve/straight	Curved road section, Not curved or unknown
Pedestrian involved Crash	Yes or No
Hit object/animal crash	Yes or No
Cornering	Yes or No (defined by DCA codes)
Cornering*Single vehicle	Single motor vehicle crash and cornering Not a Single motor vehicle crash or Not cornering
Rider sex ¹⁴	Male , Female, Unknown
Helmet worn	Yes or No/unknown/not applicable
Rider Age	0-24, 25-59 , 60+, Unknown
Rider License Type	Learner, Provisional, Full or Unlicensed for VIC, SA and WA only
Record of speeding or BAC>0.05 ¹⁵	Recorded or Not Recorded
Light Conditions	Daylight , Dark, Dawn/Dusk, unknown
Weather	Wet/Snow/fog mist, Dry

¹³Only 24,410 cases if engine size were included. So to be true to "Full" status, engine size was not included in this analyses. Also, licence status was included in an analysis of just VIC, SA and WA data.

¹⁴Included in all models, although not usually significant.

¹⁵Speeding records only for NSW, Alcohol only for QLD and VIC.

Year of Manufacture ¹⁶	1990 through to 2014
Crash Type	Single motor-vehicle: run-off road
	Single motor-vehicle: not run-off road and not loss of control
	Single motor-vehicle: not run-off road and loss of control
	Multi motor-vehicle: turn-in-front-of
	Multi motor-vehicle: cross-in-front-of
	Multi motor-vehicle: head-on
	Multi motor-vehicle: Sideswipe/lane change
	Multi motor-vehicle: rear-end
	Multi motor-vehicle: other

¹⁶The year of manufacture was included in full models although never significant.

PART 4 RESULTS

4.1 Summary – Descriptive Analysis

Distribution of all registered motorcycles averaged over 2005-2014, restricted to year of manufacture from 1990 and RVCS matching and the jurisdictions of NSW and VIC

- **54%** of registered motorcycle were learner (LAMS) approved:
 - about half of 251-749cc motorcycles were learner approved
 - 70% of 51-150 kW/t motorcycles were learner approved
- almost **half** had a power-to-weight ratio (PWR) in the range 51-150 kW/t
- about a **third** had the engine capacity ranges of:
 - 750+,
 - 251-749
 - 60-250cc
- just over a **quarter**:
 - had a power-to-weight ratio of 151-349 kW/t
 - were of the types
 - off-Road
 - sport
- **>20%** were classed as Cruisers
- **20%:**
 - had a power-to-weight ratio of ≤ 50 kW/t
 - were motorcycles aged 3-5 years (in 2014)
- **<20%** (in 2014) were motorcycles aged under 3 years
- approximately **15%** (in 2014) were motorcycles aged:
 - 11-15 years
 - 16 years and over
 - these had greater proportions of injury crashes in:
 - ❖ 60 to 250 cc sizes
 - ❖ male riders
 - ❖ learners and unlicensed riders
- **10%** were classed as:
 - road
 - scooter
- **7%** had a power-to-weight ratio of 350 kW/t or more
- **0.9 to 1.7%** had an engine capacity of 60cc or lower

Trends in registered motorcycles over time: 2005-2014

- The proportion of registered motorcycles decreased slightly for those with:
 - engine sizes 60-250 cc
 - PWR of 151-350 kW/t
- There were increased motorcycle registration numbers for:
 - NSW & VIC
- The proportion of registered motorcycle increased for those with:
 - aged 6 -15 years
 - PWR 350 kW/t and more
 - 750+ cc engine capacity (slightly)
 - LAMS approval status, from 50 to 54% over the ten years (RCVS matched cases only)

Distribution of motorcycle injury crashes (all jurisdictions averaged over 10yr period)

Overall

- just **under half** of riders received serious injuries
- just **over half** of injury crashed riders received minor injuries
- **65%** of injury crashes occurred in metropolitan regions
- over **40%** of injury crashes were at intersections
- just **over a third** of injury crashes occurred in rural regions
 - more for fatal and serious injury crashes

Riders

- approximately **80%** of riders had their full licence, 15% had probationary/learner licence
- approximately **70%** of riders were aged 25-59
- just **under a quarter** of riders were aged under 25
 - the least proportions were found for mid-range motorcycle age groups
- **10%** of injury crashed riders were female
 - females tended to lower proportions with greater motorcycle age
 - males tended to increased proportions with increases in motorcycle age
- **7%** of injury crashed riders were:
 - aged 60 or more
 - (these tended to increased proportions with increases in motorcycle age)
 - unlicensed
- **3%** have injury crashed riders
 - not wearing a helmet
 - with fatal injuries

Crash types, speed zones and road conditions

- just **under 60%** of injury crashes involved another vehicle
- **>80%** of injury crashes happened in the daytime
- **almost half** of injury crashes occurred in speed zones of 51-79 km/hr
 - less for fatal and serious injury crashes
- just **under 30%** of injury crashes occurred in speed zones of
 - 80 or more km/hr
 - (more for fatal and serious injury crashes)
 - 50 or under km/hr
 - (less for fatal and serious injury crashes)
- just **under 30%** of injury crashes occurred at curves
- **20%** of injury crashes involved one vehicle turning in front of another, and 20% cornering
- **12%** of injury crashes happened on wet roads

Trends in injury crashes involving motorcyclists over time: 2005-2014

- minor injury crashes exhibited only slightly higher frequencies than *fatal and serious* injury crashes
- **decreased** overall injury crash counts, and by jurisdiction for QLD
- **decreased** proportions of injury crashes for riders:

- not wearing helmets
- aged under 25 years
- increased overall injury crash counts for NSW
- increased proportions of injury crashed motorcycles where:
 - rider was female
 - rider was aged 60+ years (more than doubled)
 - rider was unlicensed
 - speed zone is 50km/hr and under
 - conditions are wet
 - light conditions are dark (night)

4.2 Summary – Logistic Regression Analysis

Trends in motorcycle injury and fatal and serious injury crash rates or risk over time: 2005-2014

- After correcting for motorcycle attributes, and registration year, the risk (probability) of a motorcycle injury crash, in both NSW and VIC remained stable over the 10 year period:
 - at about 1 % (1 per 100 registrations) for injury crash risk;
 - at about 0.5 % (1 per 200 registrations) for fatal/serious risk.
- Decreased raw injury crash and severe injury crash rates generally:
 - Steeper rates of decline for small capacity (<60cc) motorcycles
 - (which also decreased with motorcycle age);
 - motorcycles with power-to-weight ratios of 350+ kW/t
 - (for both injury and fatal and serious injury rates).
- Increased raw injury crash rates for:
 - Probationary riders;
 - Riders aged 60 years and over (almost doubled over the period).

Motorcycle characteristics and injury crash risk: 2005-2014

- decreasing odds of an injury crash associated with increases in:
 - year of manufacture for each year after 2007 (relative to 2005)
 - engine capacity (adjusted for PWR)
 - 2.9% ($p<0.0001$) with each **1 cc increase**
 - with or without adjusting for Redbook type and without interaction of type with engine size (Changes in this odds ratio also varied by Redbook type)
- increasing odds of an injury crash associated with increases in:
 - power-to-weight ratio
 - 2.0% ($p<0.0001$) for each **10kW/t increase** (0.9% if also adjusted for Redbook type)
- odds of an injury crash were higher by:
 - 38-90% for **Enduro (off-road)**, **Sport** and **Naked** types, relative to all other types ($p<0.0001$)
- highest injury crash rate by category for:
 - motorcycle ages aged <3years
 - motorcycles with PWR of 350 kW/t or more
 - (rates were approximately double that of the other engine capacity groups)
 - type were Sport, Scooter and Naked types
- learner approved injury crash rates were higher relative to not approved¹⁷ motorcycles for:
 - 51-150 kW/t PWR motorcycles
 - speed zones ≤50 km/hr
 - wet roads
- lowest injury crash rate by category (within a crash variable) for:
 - motorcycles aged 16 years and over
 - engine sizes up to 60cc
 - off-road types

¹⁷Usually LAMS not approved had the higher crash rate

- Injury crash rates were halved for riders aged 25 and over if the motorcycle was learner approved.
- Odds of an injury crash were **lower** by:
 - **17%** for **Victoria**, relative to NSW ($p<0.0001$);
 - **43%** for motorcycles with **up to 60cc** engine capacity¹⁸, relative to the motorcycles of the 251-749cc capacity group, ($p<0.0001$), which was not significantly different from the group of >750 cc capacity motorcycles;
 - **14%** for **learner approved motorcycles**, relative to Not Approved ($p<0.0001$);
 - **25-38%** for only **Touring** and **Off-Road** types, relative to all other types ($p<0.0001$).

Motorcycle characteristics associated with fatal and serious injury crash risk: 2005-2014

- **increasing** odds of a fatal or serious injury crash were associated with:
 - **increased power-to-weight ratio (PWR)**
 - by **2.1%** ($p<0.0001$) for each **10kW/t increase** (1.2% if also adjusted for Redbook type)
 - **larger engine capacity categories** (without PWR adjustment)
- **decreasing** odds of a fatal or serious injury crash associated with:
 - **newer motorcycles (by year of manufacture)** for each year after 2007 (relative to 2005)
 - **great engine capacity** adjusted for PWR:
 - **0.007%** ($p=0.008$) with each **1 cc increase** without adjustment for Redbook type
 - **0.016%** ($p<0.0001$) with each **1 cc increase** with adjustment for Redbook type
 - (Changes in this odds ratio also varied by Redbook type)
- Odds of a fatal or serious injury crash were **lower** by:
 - **56%** for motorcycles with **up to 60cc** engine capacity¹⁹, compared to 251-749cc motorcycles, ($p<0.0001$);
 - **32-42%** for only **Touring** and **Off-Road** types compared to all other types ($p<0.001$);
 - **30%** for **LAMS approved motorcycles** cf. Not Approved ($p<0.0001$);
 - **12%** for motorcycles with **60-250cc** engine capacity²⁰, relative to the 251-749cc motorcycles, ($p<0.0001$);
 - **7%** for **Victoria**, relative to NSW ($p<0.0001$).
- Odds of a fatal or serious injury crash were **higher** by:
 - **26-103%** for **Enduro**, **Sport** and **Naked** types, cf. all other types ($p<0.056$);
 - **14%** for **750+cc** engine capacity²¹, relative to 251-749cc engines, ($p<0.0001$).
- highest fatal and serious injury crash rate by category (within a crash variable) for:
 - motorcycles with a power-to-weight ratio of 350+ kW/t (rates approximately double that of the other engine capacity groups)
 - motorcycles aged <3 years
- lowest crash rate by category (within a crash variable) for:
 - motorcycles aged 16 years and over
 - engine sizes up to 60cc

Trends over time relating to the severity of an injury crash: 2005-2014

- crash severity **increased** (up to 80%) over the 10 year period
 - using the **full** model, the odds of a severe injury crash outcome peaked in 2013 at 1.83 times the 2005 risk (95% CI: 1.67, 1.99, $p<0.0001$)

Factors effecting severity of an injury crash

- **increasing** odds of a more severe injury crash outcome were associated with:
 - **larger engine capacity**
 - by **0.026%** ($p<0.0001$) with each **1cc increase** with no significant interaction with bike type
 - **higher power-to-weight ratio**
 - by **0.05%** ($p<0.048$) with each **10kW/t increase**
 - increasing rider age
 - higher speed zones (by category)
 - multi-vehicle crashes (relative to single vehicle)
- The odds ratio of a more severe injury crash outcome were **higher**:

¹⁸No adjustment for PWR and engine size in categories

¹⁹No adjustment for PWR and engine size in categories

²⁰No adjustment for PWR and engine size in categories

²¹No adjustment for PWR and engine size in categories

- by **68%** ($p=0.0003$) if cornering and multi-vehicle (cf. not cornering);
 - by **49%** ($p<0.0001$) if speed zone was 80 km/hr and over (cf. 51-79km/h);
 - by **48%** ($p=0.007$) if the crash region was remote (relative to rural);
 - by **32%** ($p<0.0001$) if in dark conditions (relative to light);
 - by **12%** ($p=0.0048$) if in dawn/dusk conditions (relative to light);
 - by **6%** ($p=0.0014$) if cornering and single-motor vehicle (cf. not cornering);
 - by **39%** ($p<0.0001$) if the rider was aged 60 years or over (cf. 25-59 years);
 - by **72%** ($p<0.0001$) if the rider was not wearing a helmet;
 - by **25%** ($p=0.02$) if the rider was unlicensed (relative to full licence);
 - by **12%** ($p=0.035$) if the rider was a learner (relative to full licence);
 - by **44%** ($p=0.0002$) if a pedestrian was involved (relative to not);
 - by **16%** ($p<0.0001$) if an object or animal was hit (relative to not);
 - by **5-13%** for **Cruiser** and **Off-Road**, relative to all other types ($p<0.003$);
 - in **QLD** and **VIC** relative to **NSW**.
- The odds ratio of a more severe injury crash outcome were **higher** relative to single vehicle on carriageway loss of control crashes:
 - by **3.36** times ($p<0.0001$) if head-on;
 - by **1.95** times ($p<0.0001$) if turn-in-front-of;
 - by **1.70** times ($p=0.005$) if cross-in-front-of;
 - by **29%** ($p=0.0003$) if other multi-vehicle;
 - by **18%** ($p<0.0001$) if rear-end;
 - by **8%** ($p<0.0001$) if sideswipe/lane change.
 - The odds of a more severe injury crash outcome were **lower**²²:
 - by **34%** ($p<0.0001$) if the single motor vehicle crash was on the carriageway and involving loss of control (cf. single vehicle run-off road);
 - by **27%** ($p<0.0001$) if the single motor vehicle crash was on the carriageway and not involving loss of control (cf. single vehicle run-off road);
 - by **19%** ($p<0.0001$) if crash was in wet/foggy/snowy weather (cf. dry);
 - by **12%** ($p<0.0001$) if crash was at an intersection (cf. not at intersection);
 - by **11%** ($p<0.0001$) if the rider was under 25 years of age (cf. 25-59yrs);
 - by **11%** ($p<0.0001$) if speed zone was 50 km/hr and under (cf. 51-79km/h);
 - if rider left (cf. staying on) the carriage way for single vehicle crashes;
 - in **SA** relative to **NSW**.

²²After adjusting for other covariates such as motorcycle and rider attributes, jurisdiction, registration year and crash types.

Risk Characteristics by Redbook type

TABLE 8 RISK CHARACTERISTICS BY REDBOOK TYPE

Ranks are highest/most to lowest/least * = all injury crashes * = minor injury crashes X = fatal and serious injury crashes reg = registrations

↑ indicates that the odds of an injury crash increases with engine capacity. If there is no arrow, then the OR decreases with engine capacity increases.

	Rank of		odds of an injury crash	raw injury crash rates			proportion of LAMS approved (Registrations or crashes)	Highest crash rates			Highest proportions of injury crashes				
	odds of an			all	11-15 yo veh	<3yo vehicle		single vehicle	metropolitan	rural	intersection	riders	Female	Probationary	
	Registrations	fatal or more serious injury crash	most sensitive to engine capacity	highest	lowest	highest	highest	lowest	lowest	highest	<25yo	60+yo		Learner	Unlicensed
Sport	2	2	2	4	X **	**	**	**	reg, **	**	**	**	X **	X **	X **
Off-Road	1	12	12	1	X ** ↑	**	**	**	reg, **	**	**	**	X **	X **	X **
Cruiser	3	9	5	2	**	**	**	**	reg, **	**	**	**	X		
Road	4	10	10	5	** ↑	**	**	**	reg, **	reg, **	**	**	X	X X	X X
Scooter	5	5	7	6		**	**	**	reg, **	reg, **	**	**	X X	X X	X X
Touring	6	11	11	7	**	**	**	**	reg, **	**	**	**	*		
Naked	7	3	3	3	**	**	**	**	reg, **	**	**	**	X X	X X	X X
Adventure	8	4	4	-					reg, **		**	**	*		
Enduro	9	1	1	-	X **				reg, **	**	**	**			
Classic	10	8	6	-					reg, **	**	**	**	X X		
Motard	11	7	9	-	X ↑					**	**	**	X		X
Chopper	12	6	8	-					reg, **				X X	X X	

4.3 Changes in registrations (VIC and NSW) and injury crash rates and risk over time

Motorcycle injury crash rates per New South Wales and Victorian motorcycle registration have decreased by approximately 60% from 2005 to 2014. The green line in Figure 2 shows that registrations in NSW and VIC have increased by 74% over the period. The bars of Figure 2 were calculated from aggregated raw injury crash data and ABS adjusted registration counts.

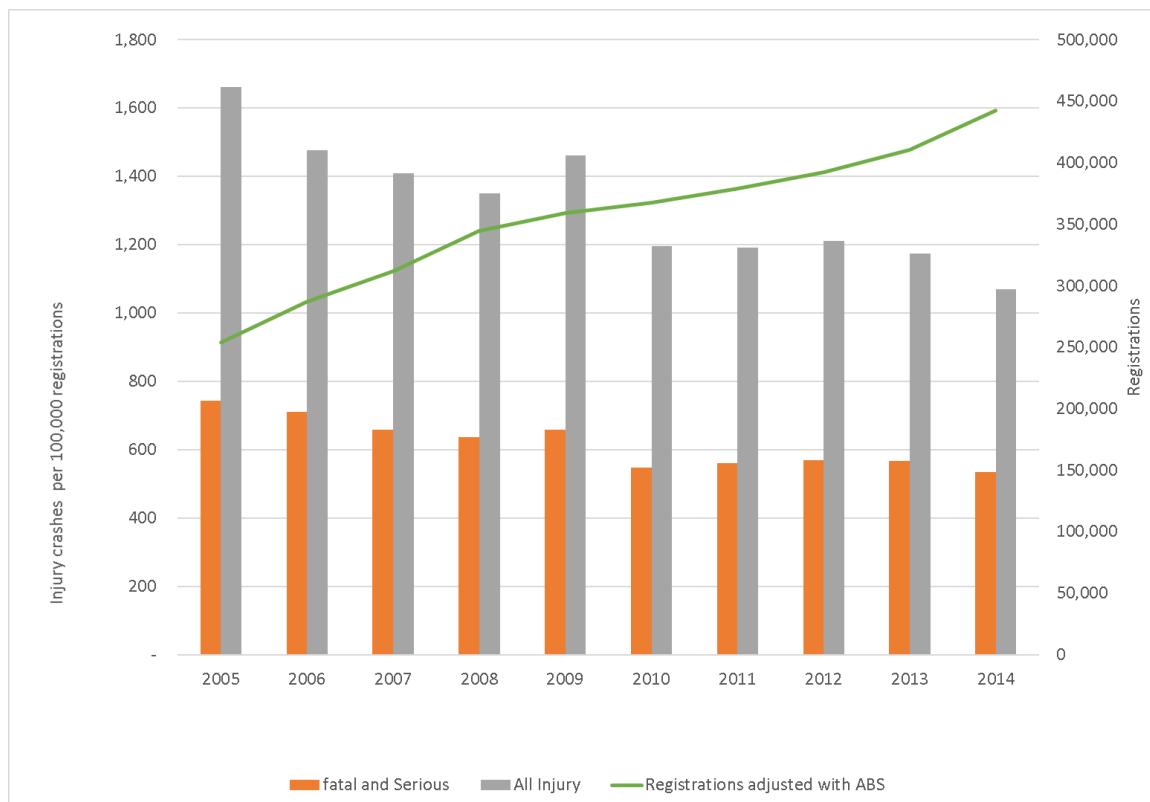


Figure 2 Injury crashes per 100,000 registered motorcycles (bars) and registered motorcycles (solid line) in NSW and Victoria

NSW appeared to have greater increases in injury crashes per year than other jurisdictions; counts of injury crashes decreased for Queensland and remained fairly stable for South Australia (Figure 3). By severity, it appeared that since 2009 both minor and fatal combined jurisdictional crash rates declined (Figure 3).

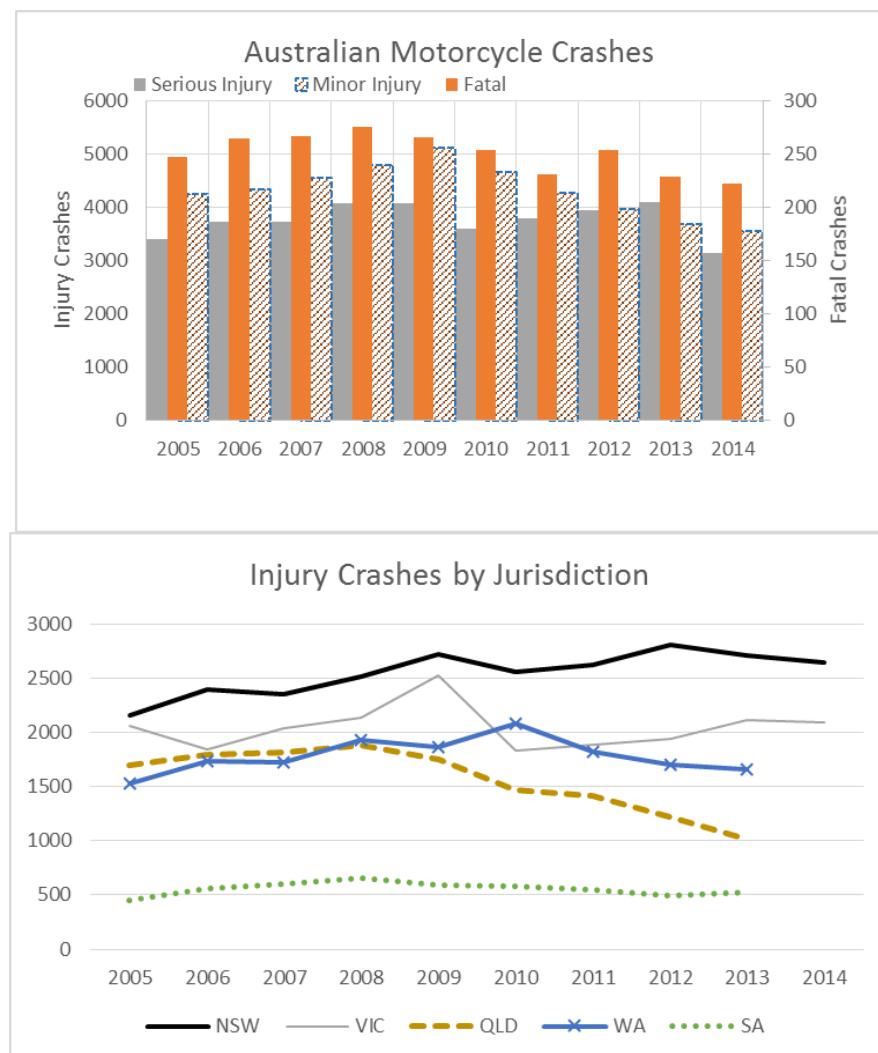


Figure 3 Australian motorcycle injury crashes by severity and jurisdiction (2005 to 2014)

Depicted in Figure 4 and Figure 5 respectively, are the plotted estimated injury crash and fatal and serious injury crash probabilities (model ii) for each jurisdiction and registration year at the mean power-to-weight ratio and (square root of) mean engine capacity. It is clear that, within a fixed jurisdiction and with fixed motorcycle attributes (including engine capacity, power-to-weight ratio and year of manufacture), the likelihood of a both injury and fatal and serious injury motorcycle crashes in the region comprising of NSW and Victoria, has actually remained fairly constant over time. Odds ratio estimates for the risk of an injury crash by registration year may be found in Appendix 8.4.

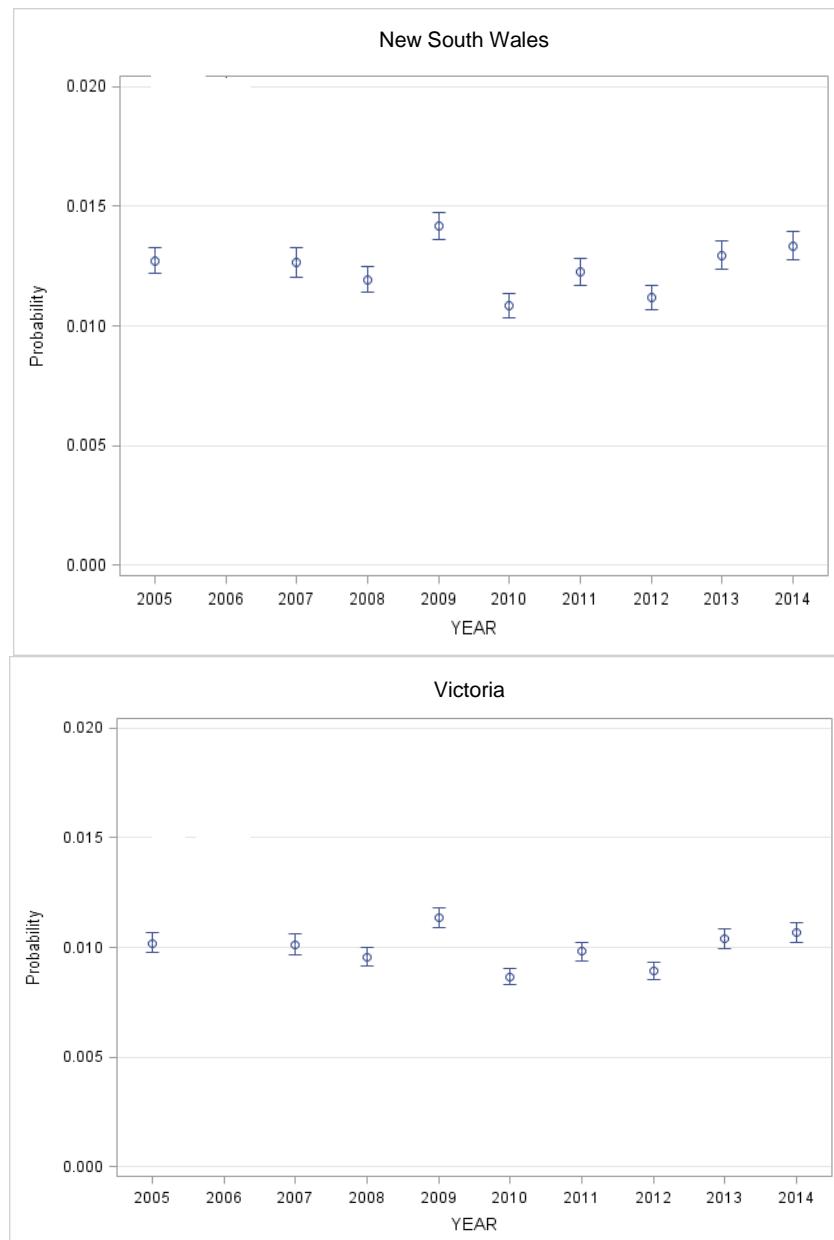


Figure 4 Predicted probability of an injury crash for each year, at average engine capacity and power-to-weight ratios for NSW and VIC ($\alpha=0.05$)

Minor injury crash frequencies were only slightly higher than the frequencies of *fatal and serious* injury crashes, so it was expected that the predicted probability of a fatal or serious injury crash, adjusted for motorcycle attributes, was just less than half of that for an injury crash.

There was an increasing trend, from 2010, of significant odds of an injury crash being more serious (Figure 6) and an increasing trend of the probability of a more serious injury crash (Appendix 8.4). The odds ratio trend has been depicted for the odds-ratio from *full* data model; however, the odds ratio for registration year from the reduced data model was virtually identical. The *full* crash data model was adjusted with the covariates listed in Section 2.

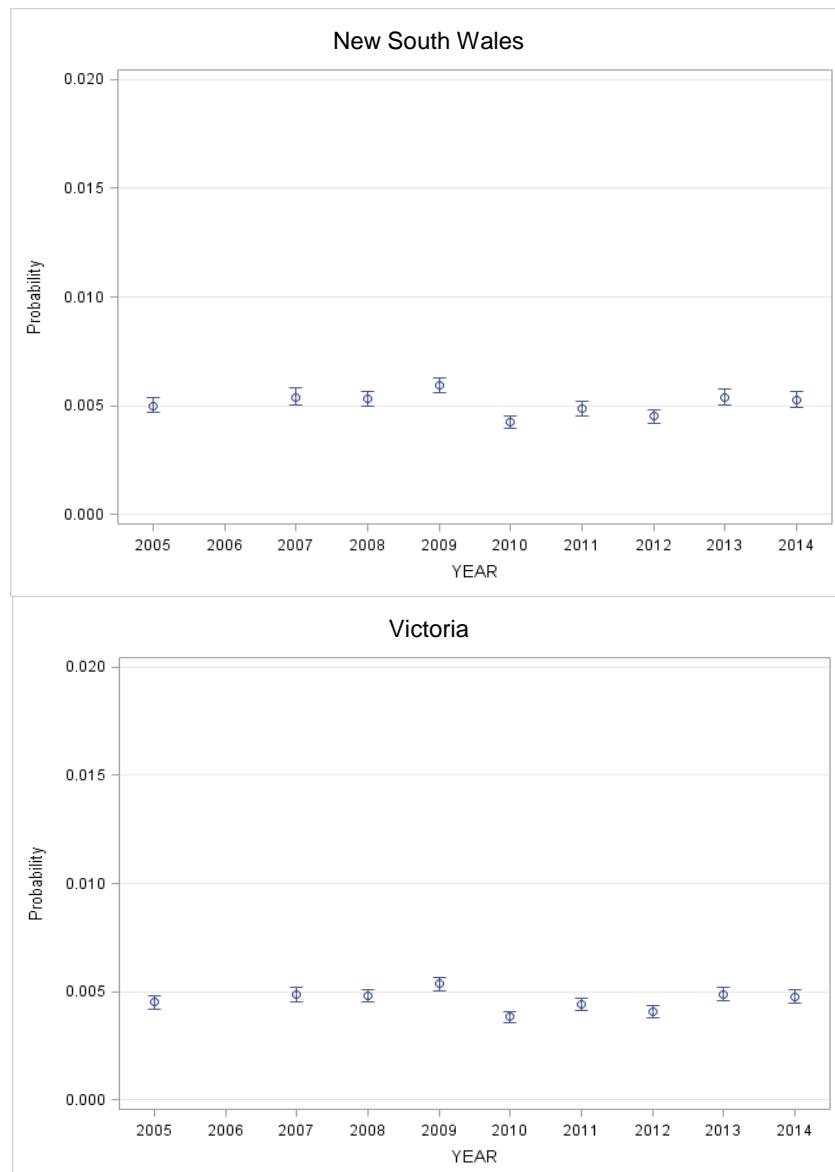


Figure 5 Predicted probability of a fatal or serious injury crash for each year, at average capacity and power-to-weight ratios for NSW and VIC ($\alpha=0.05$)

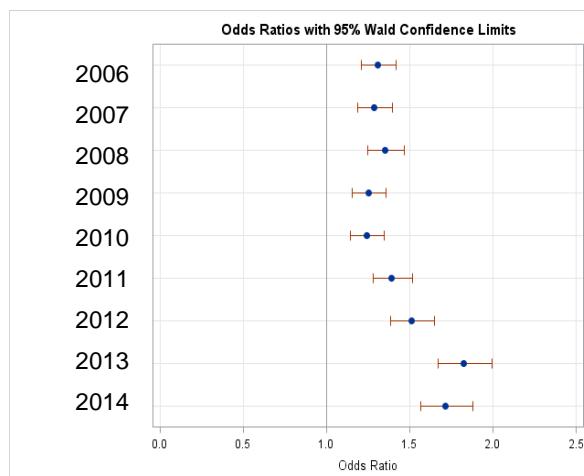


Figure 6 Crash severity odds ratios for each registration year, relative to the base year of 2005

4.4 Effects of jurisdiction

The temporal trends in injury crash frequencies were found to differ by jurisdiction (Figure 3). Jurisdictional differences were also observed in the *injury crash risk* and *crash severity* analyses. Jurisdiction was found to significantly contribute to both the odds of an *injury* and the odds of a *fatal or serious injury* crash. The odds of an *injury* crash were found to be about 20%, ($p<0.0001$) lower for Victoria than for NSW. The odds of a fatal or serious injury crash were found to be about 10 % ($p<0.0001$) lower for Victoria than for NSW.²³ The odds of a severe injury crash outcome were found to be significantly different from between jurisdictions of QLD, SA and VIC (Figure 7)²⁴. Motorcycle injury crashes in Western Australia were as likely to be fatal and serious as those in New South Wales. Motorcycle injury crashes were less likely to be as serious in South Australia than for other jurisdictions. Motorcycle injury crashes were most likely to have serious outcomes in Queensland, with twice crash severity risk as NSW.

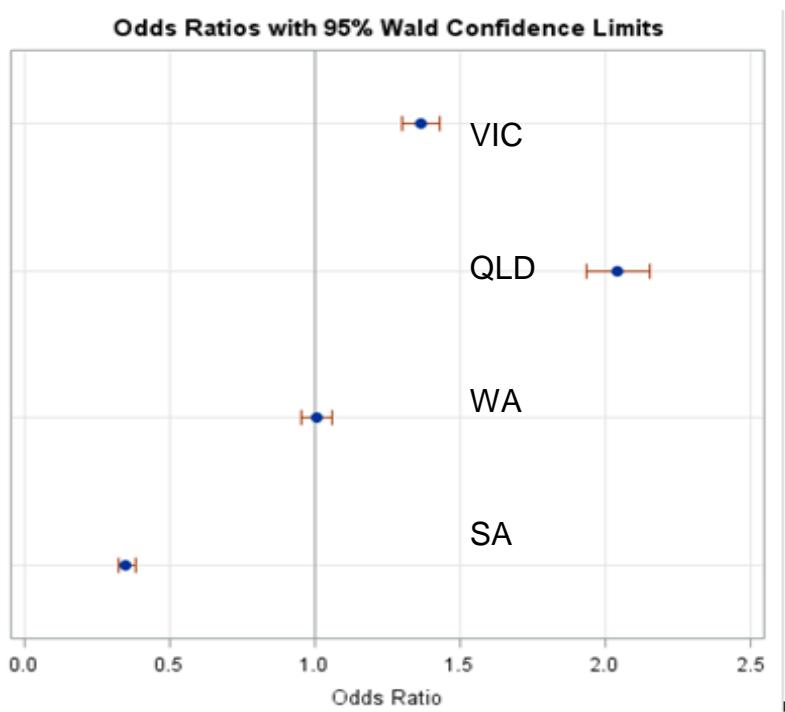


Figure 7 Crash severity odds ratios for each jurisdiction, relative to NSW

Figure 58 (Appendix 8.4) also depicts jurisdictional differences in temporal trends in the probability of a severe injury crash outcome. The same ranking as for odds ratio is observed.

4.5 Effects of year of manufacture

Motorcycle age and year of manufacture (YOM) distributions were fairly stable over the 2005 to 2014 period for the combined NSW and VIC jurisdictions (Figure 8). A small general trend for an ageing motorcycle fleet was evident over the period.

Because year of manufacture was a registration dataset variable with relatively few missing values it was used along with engine capacity as a motorcycle attribute in (fatal and serious) *crash risk* and the *crash severity* analyses. After correction for jurisdiction, registration year and engine size, the year of manufacture was significantly associated with the odds of an injury crash and the odds of a serious injury crash ($p=<0.0001$) but not to the odds of a severe injury crash outcome ($p>0.08$).

²³The odds of an injury crash were found to be 22 % (95%CI: 20-24, $p<0.0001$) lower for Victoria than for NSW using the *full* dataset and 17 % (95%CI: 14-19, $p<0.0001$) lower for Victoria than for NSW using the *reduced* dataset modelled with motorcycle type, capacity and power-to-weight ratio. The odds of a fatal or serious injury crash were found to be 12 % (95%CI: 8-15, $p<0.0001$) lower for Victoria than for NSW using the *full* dataset and 7 % (95%CI: 3-11, $p<0.0001$) lower for Victoria than for NSW using the *reduced* dataset modelled with motorcycle type, capacity and power-to-weight ratio.

²⁴The *full* dataset model odds ratio estimates and the *reduced* dataset model estimates were virtually identical.

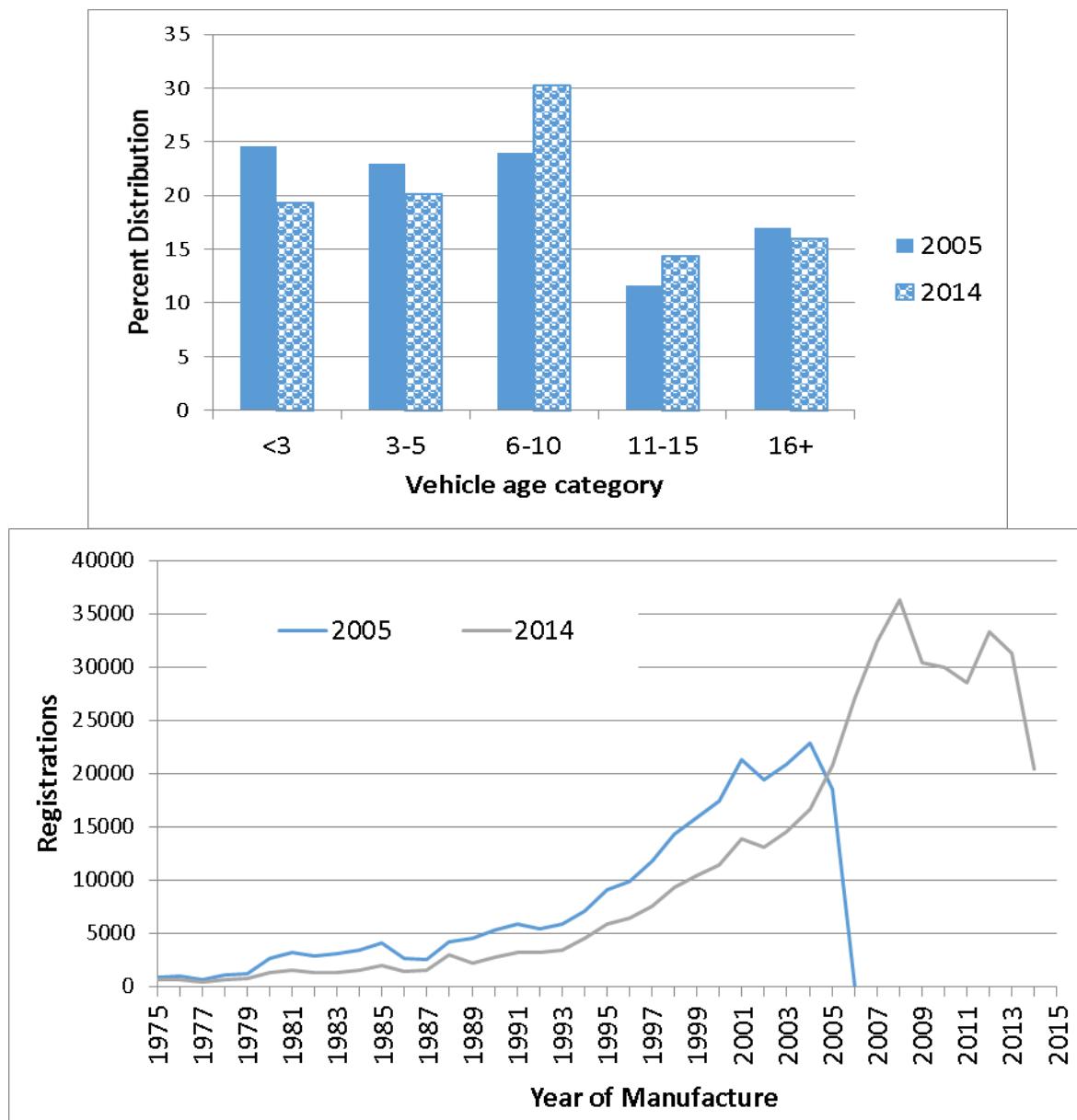


Figure 8 Distribution of motorcycle age and year of manufacture amongst NSW and VIC registered motorcycles in 2005 and 2014

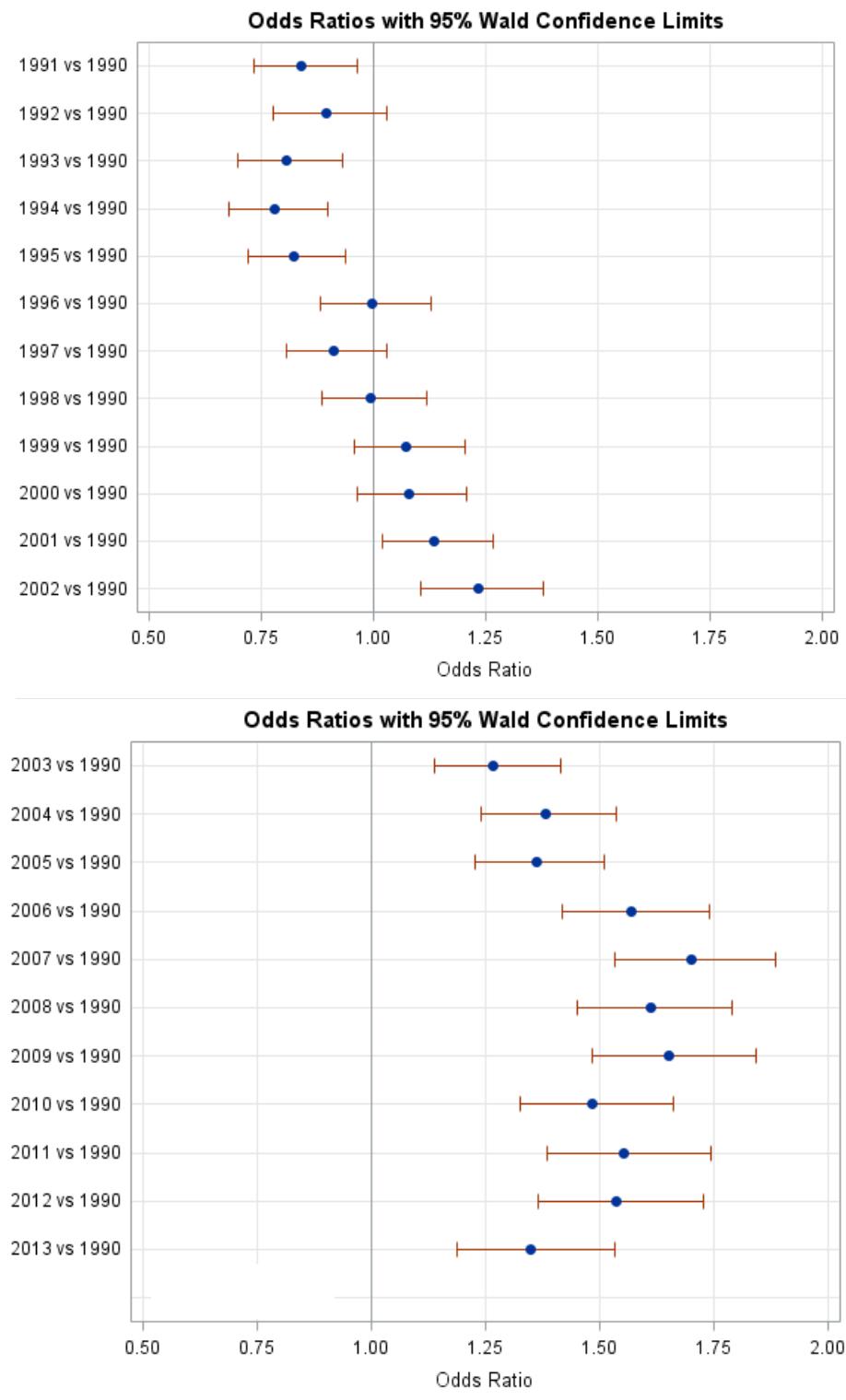


Figure 9 Odds of an injury crash for each year of manufacture relative to 1990

Adjusted for registration year and jurisdiction, the odds of an injury crash were found to increase with year of manufacture from 1990 to 2007, and decrease a little thereafter. Figure 9 displays the trend for the *full* dataset.

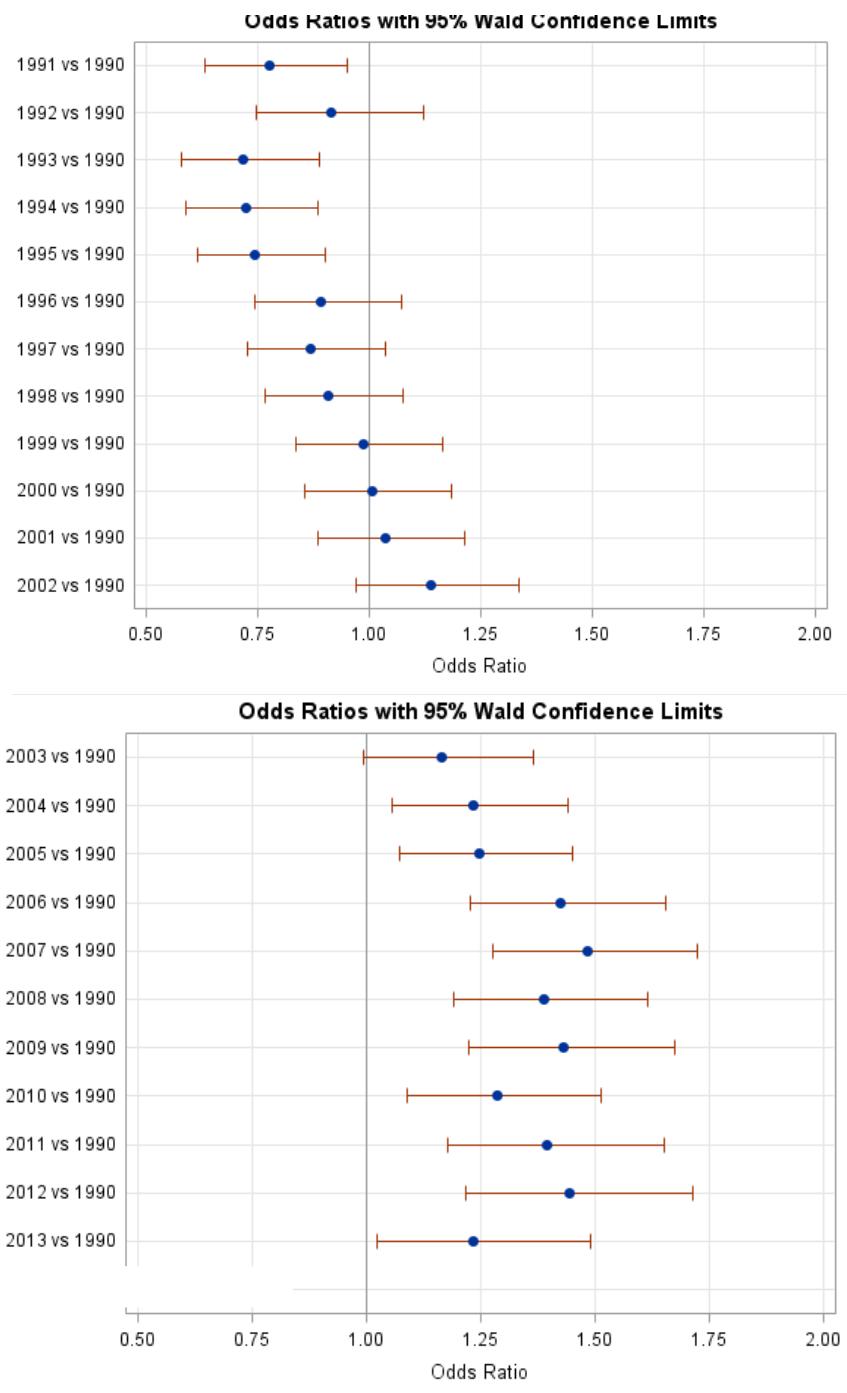


Figure 10 Odds of a fatal or serious injury crash for each year of manufacture relative to 1990

The odds of a fatal or serious injury crash were found to increase with year of manufacture from 1990 to 2007, after which they declined a little. Figure 10 displays the trend for the *full* dataset.

There were no *years of manufacture* comparisons between 1991 and 2013 which produced odds of a more severe injury crash outcome that were significantly different from that of 1990, however, from 1999, odds ratios relative to 1990 declined (Figure 11).

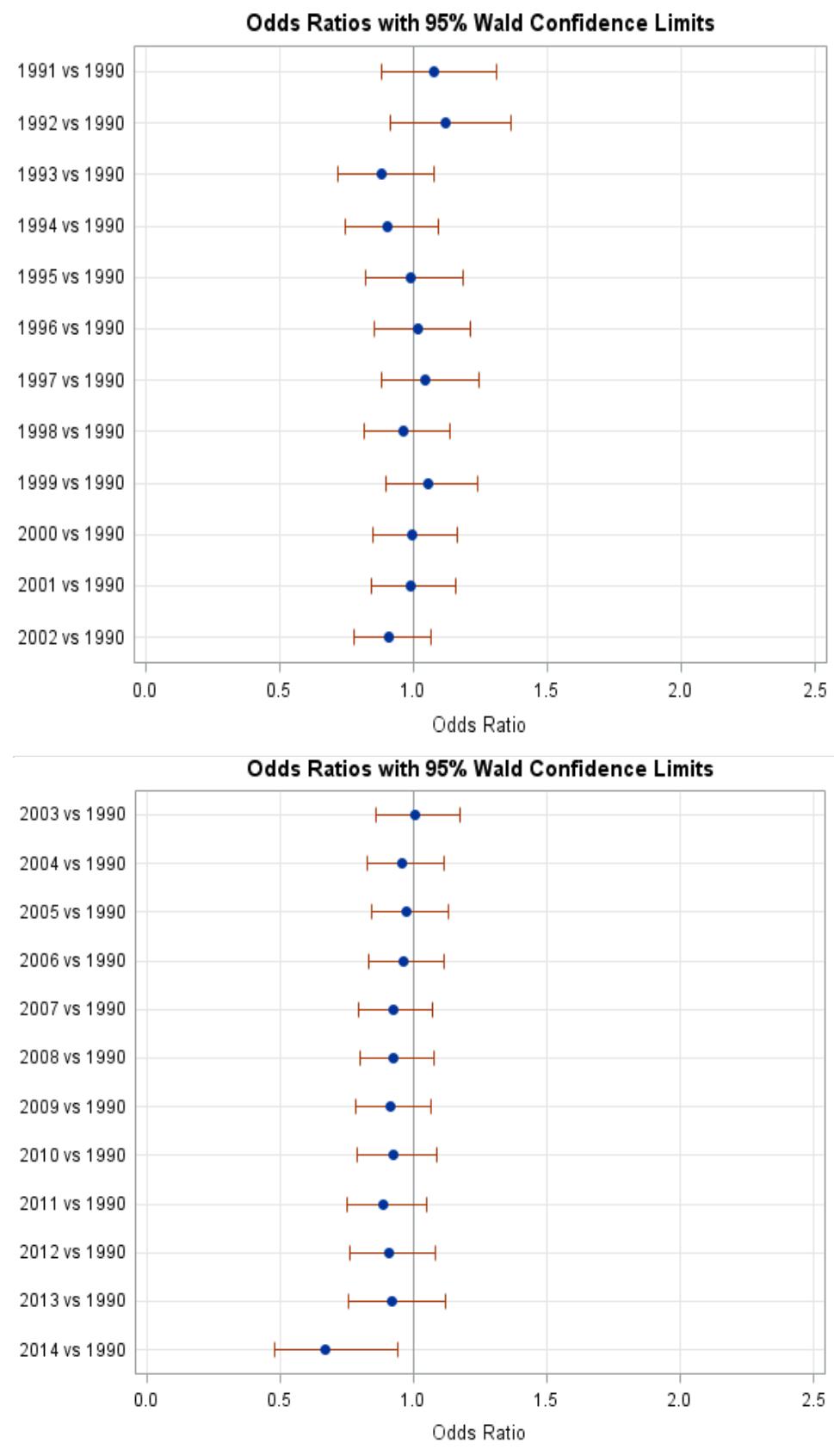


Figure 11 Odds of a more serious injury crash for each year of manufacture relative to 1990

The general trend of decreasing (fatal and serious) injury crash rates with increased age of a motorcycle is possibly reflective of the confounding effects of other motorcycle attributes such as a possible corresponding decrease in road exposure with motorcycles age (Figure 12). This explanation of confounding motorcycle attributes is supported by the finding that models using other motorcycle attributes (engine capacity, power-to-weight ratios and motorcycle type) were better predictors of injury crash risk than were models produced using year of manufacture (Appendix 6).

The dip in raw crash rates from 2007 to 2012 is due to the inflated NSW registrations provided for this period.

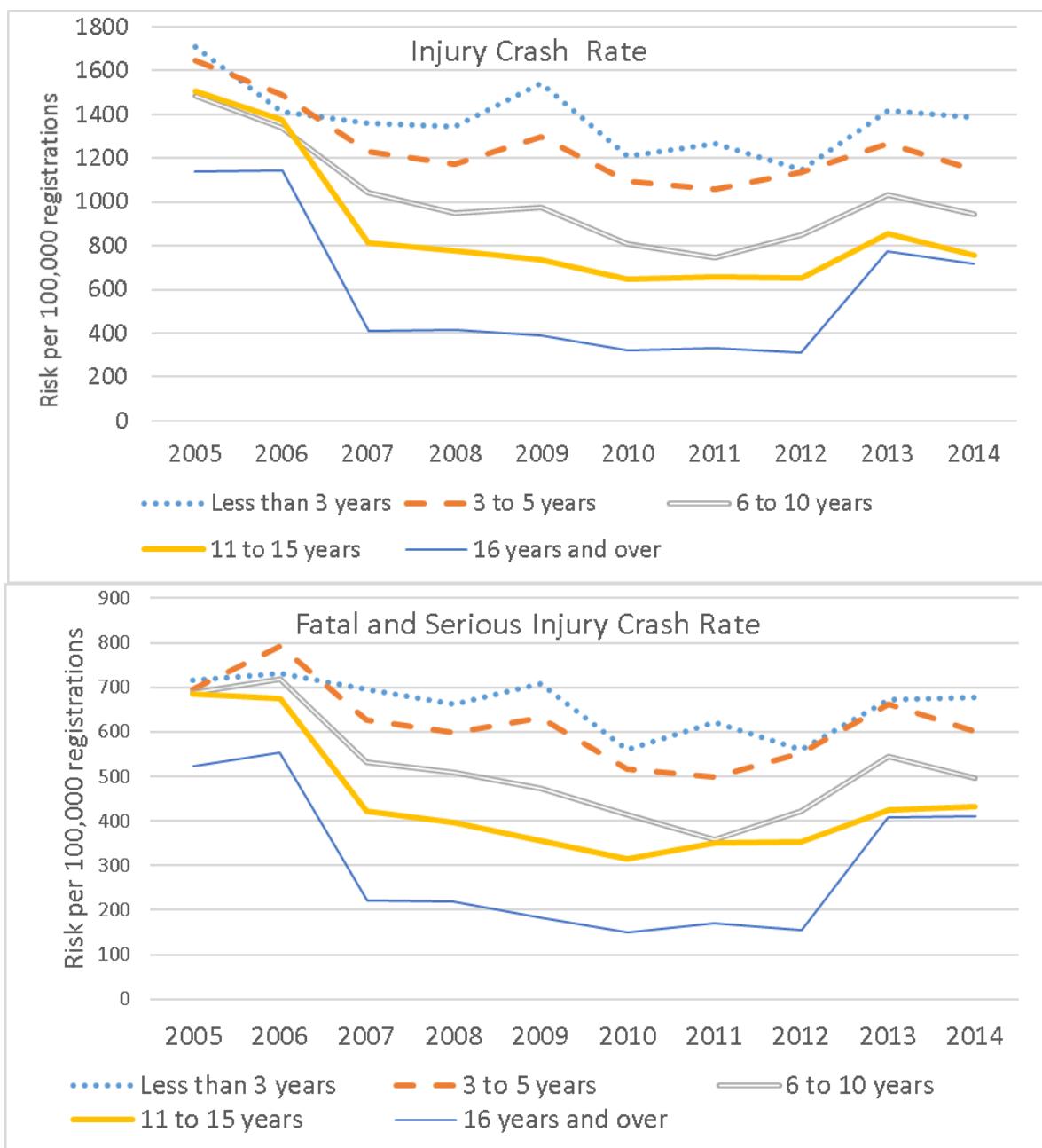


Figure 12 Injury and fatal and serious injury crash rates by motorcycle age and registration year

Rider age crash distribution was fairly stable across the motorcycle age groups, however, for older motorcycle injury crashes there were greater proportions of:

- male riders (~5% units);
- learners and unlicensed riders;
- 60 to 250cc engine sizes (Figure 13).

Regardless of motorcycle age crash rates were highest for:

- Sport and Naked types (Figure 14).

Regardless of motorcycle age, Off-road and Chopper were rated with low or lowest crash rates. The spike in crash rates for Choppers aged 11-15 years is reflective of random variation within sparse data.

Newer motorcycle crash rates were lowest for

- Adventure (Figure 14).

The proportion of injury crashes in the lowest motorcycle age group was higher (than other motorcycle age groups),

- for probationary riders and for motorcycles with a less than 60 cc engine size.

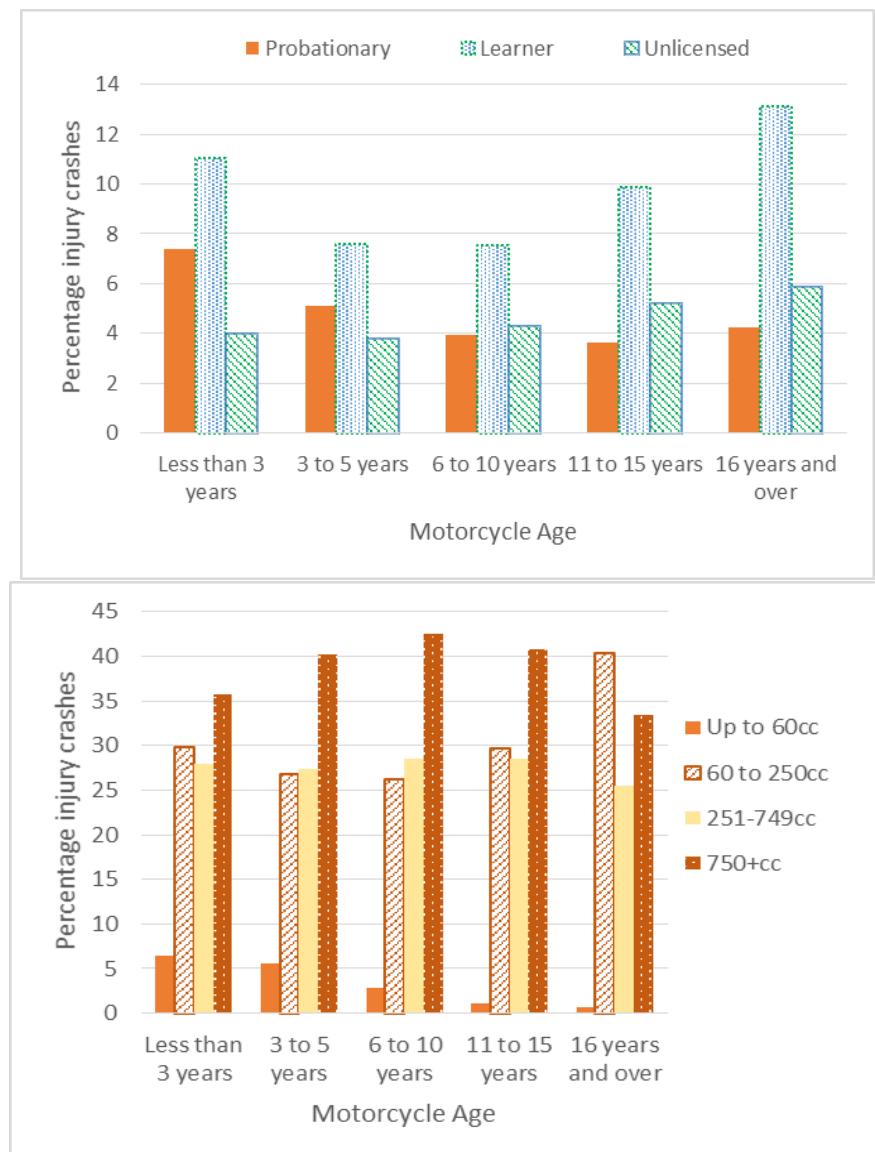


Figure 13 Ten year average injury crash distribution by motorcycle age and rider licence type or engine size

Over 2005 to 2014, the average age of an injury crashed motorcycle is 7 years.

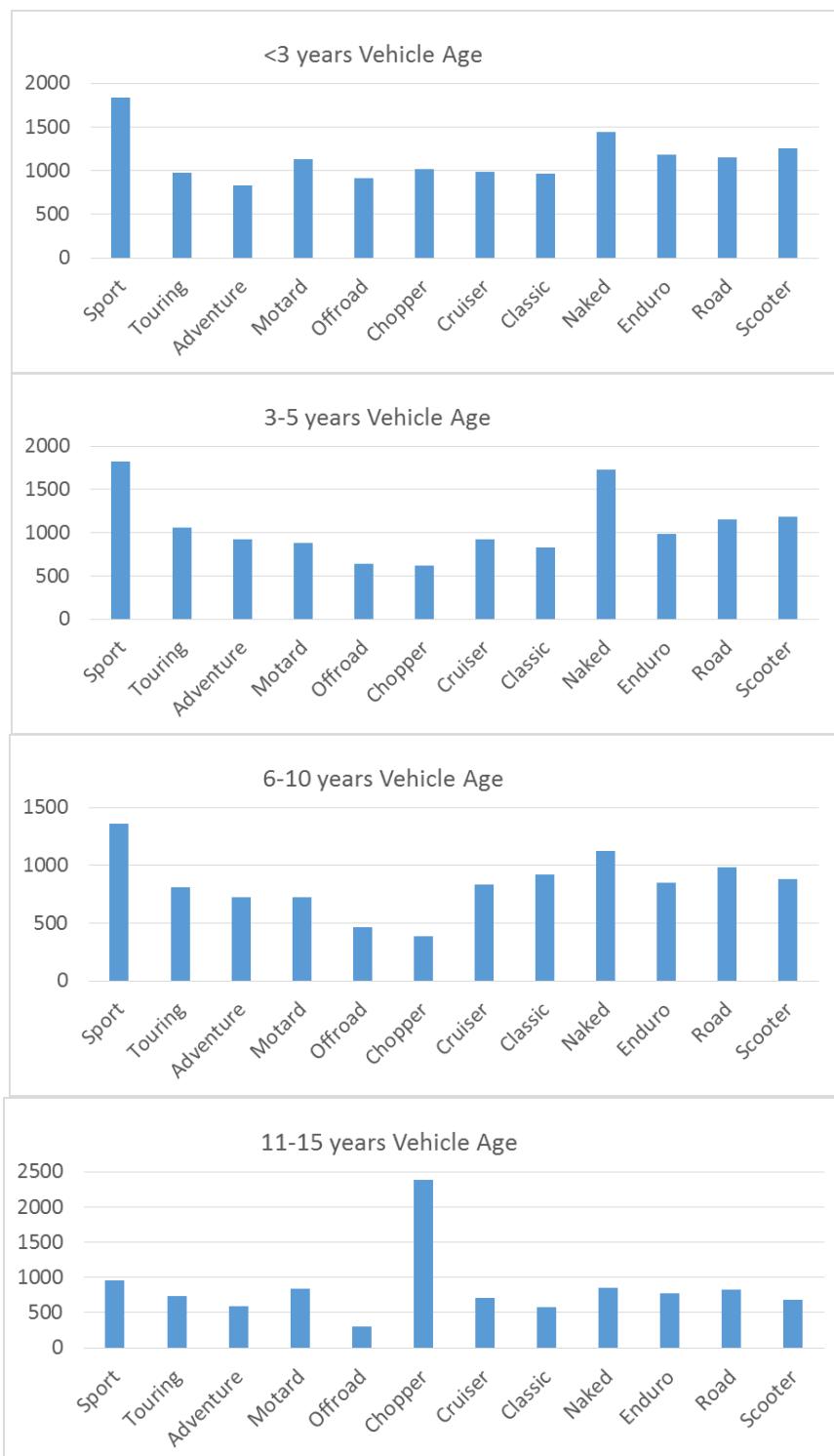


Figure 14 Ten year average injury crash rates per 100,000 registrations by motorcycle age and Redbook type²⁵

²⁵ Registrations were disaggregated by Redbook type and motorcycle age. "Offroad" excludes Enduro types.

4.6 Effect of engine size

The annual distribution of motorcycle registrations by engine size appeared similar and stable for motorcycles with engine capacities of 251 to 749 cc (Figure 15). From 2006, a slight decline in the proportion of registrations was evident for the 60-250cc group. To complement this, there was a rise in the proportion of 750+cc registrations. Motorcycles sized up to 60cc made up only 0.9 to 1.7% of total registrations. The remaining engine size categories each represented approximately one third of registrations. Just over half of the injury crashed and the registered motorcycles in the 251-749 cc range were learner approved. Within the 60-250 cc group, 99% of registered (or crashed) motorcycles were learner approved. Within every applicable category, LAMS status was associated with lower crash rates (Figure 15).

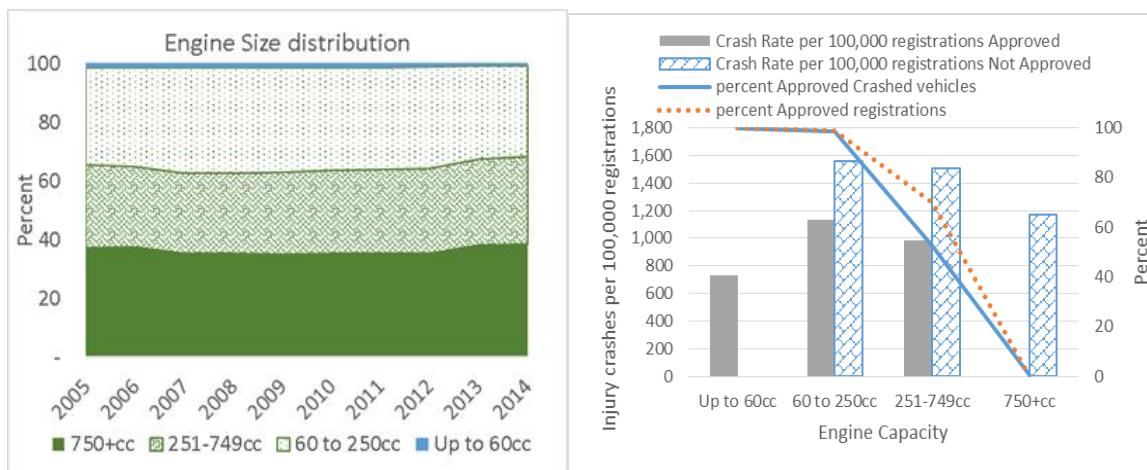


Figure 15 Stacked distribution of engine size amongst RVCS matched registration data²⁶ (2005 to 2014) and Average Injury crash rates per 100,000 registrations by LAMS status and engine capacity

Generally, injury (and fatal and serious injury) crash rates by engine size category, for categories greater than 60cc, were similar (Figure 16). The *up to 60cc* group had both lower and more rapid decreasing (fatal and serious) injury crash rates. These decreases may have been attributable to decreasing on-road exposure, increasing (confounded) rider experience as well as improvements in road infrastructure and changing speed limits and speeding behaviour over time.

Again, the dips in the raw crash rates observed between 2007 and 2012 are due to inflated NSW registrations.

The relatively small proportion of crashed motorcycles of small capacity (60cc engine size and under) meant that temporal changes in engine size for this category could not be examined separately within the crash risk regression analyses. Given the very small contribution of this group to the registered motorcycle fleet, its different trend in crash rates over time is unlikely to have significantly impacted the contribution of engine size (as a continuous variable) to injury crash risk within the logistic regression analyses.

²⁶Only cases without missing engine size. The percent of unknown engine size decreased from 22% to 2% over the ten years in vehicles with a year of manufacture greater than 1989.

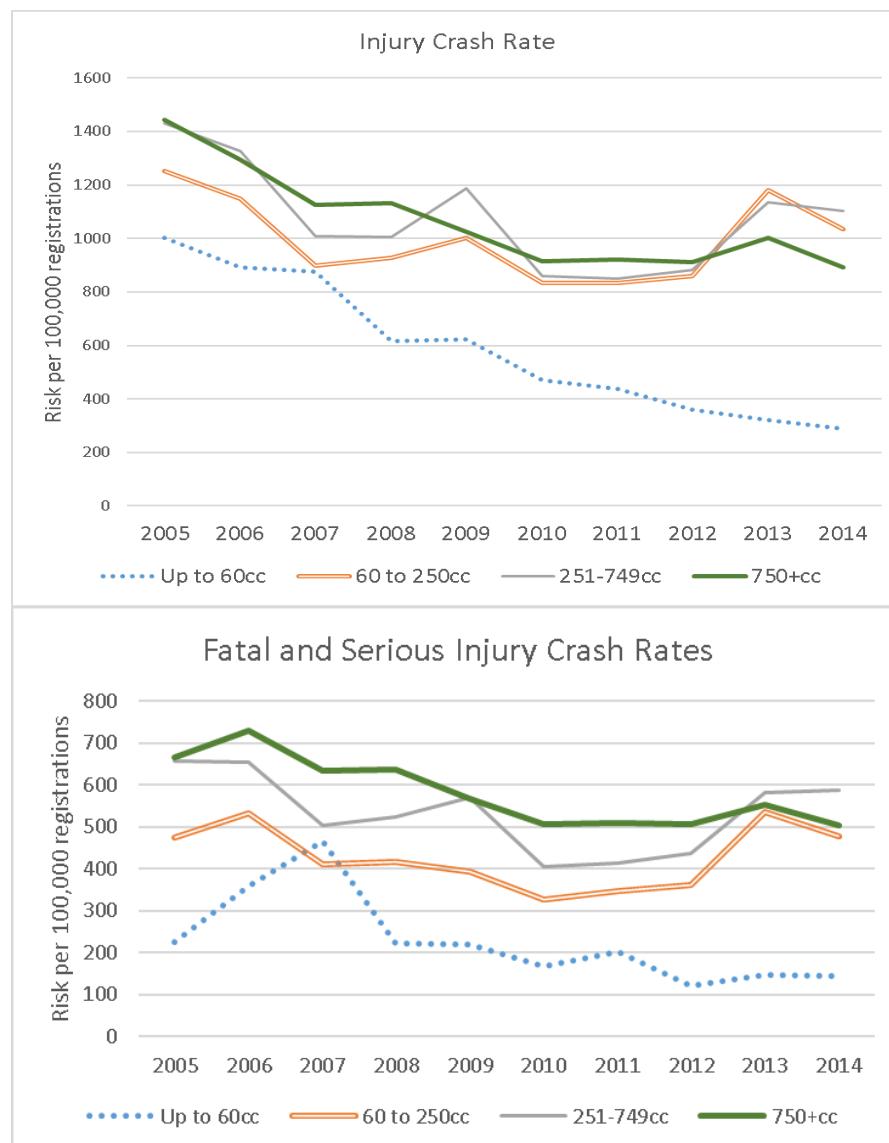


Figure 16 Injury and fatal and serious injury crash rates per 100,000 registrations by engine size categories

When adjusted for jurisdiction, year of manufacture and temporal effects, there were significant differences in the odds of an injury (or fatal and serious injury) crash by engine size categories ($p<0.0001$) (Figure 17). Motorcycles up to 60 cc were found to have a significant, 43% lower (95%CI: 35-50) odds of an injury crash than the 251-750 cc group. Other engine categories exhibited injury crash odds that were not significantly different from one another. Compared with the 251-749 cc group, there was a significant trend for increasing fatal and serious crash risk with increasing engine size:

- the up to 60 cc group had odds 56% lower (95%CI: 45-65, $p<0.0001$);
- the 60-250 cc group had odds 12% lower (95%CI: 8-16, $p<0.0001$);
- the 750 cc and above group had odds 14% higher (95%CI: 9-19, $p<0.0001$).

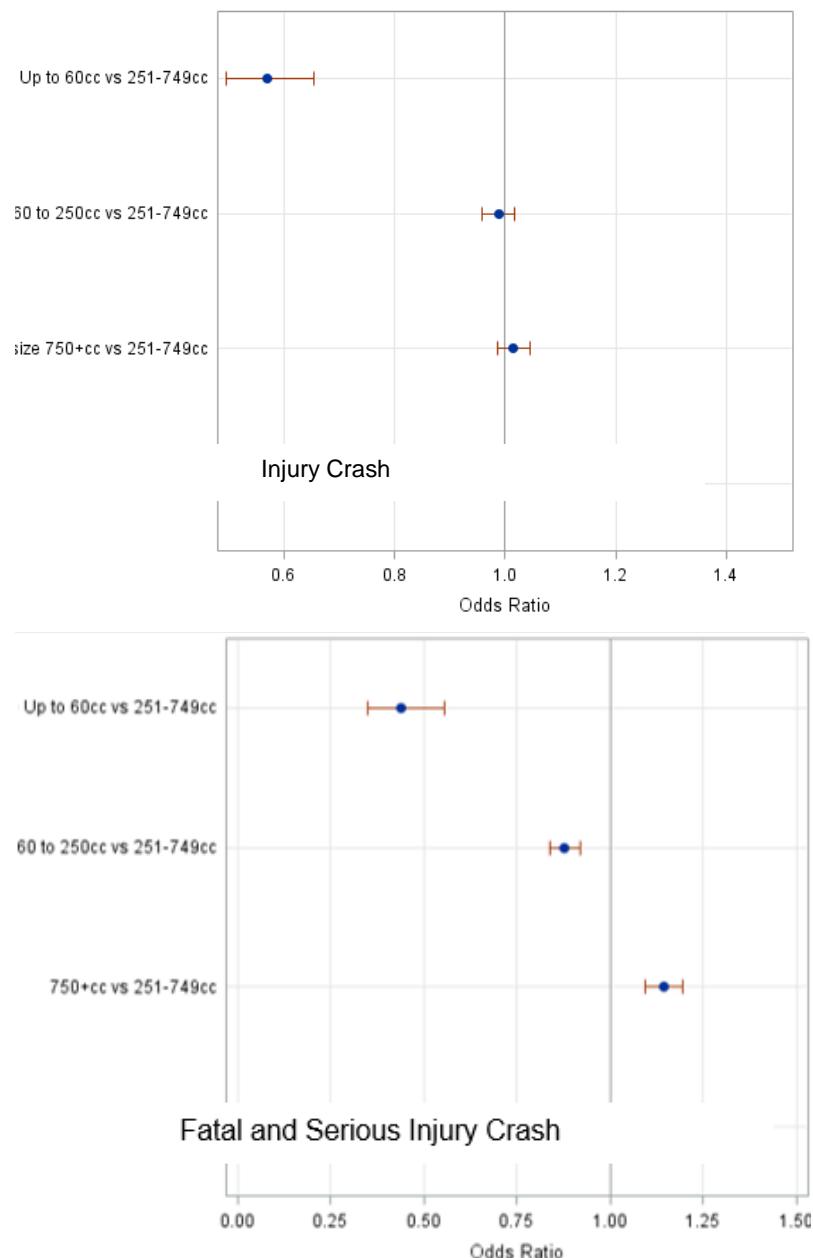


Figure 17 Odds of an injury and of a fatal or serious injury crash for each engine size category relative to the 251-749 cc categories

For both the analyses of both the *full* and the *reduced* datasets, engine size was a significant contributor to the models of the *odds of an injury crash* and the *odds of a fatal and serious injury crash*, although the engine capacity effects were reversed when the analyses also adjusted for the power-to-weight ratio. Upon the addition of PWR to the injury crash risk regression models, an association between engine size and the odds of an injury crash was estimated; this relationship was not previously evident for motorcycles categorised in sizes above 60 cc. This was a decreasing effect with increasing engine capacity. Upon the addition of PWR to the fatal and serious injury crash risk regression model the relationship between engine size and the estimated odds ratio for a fatal and serious injury crash was diminished to the extent that the estimate became one estimating essentially no relationship. Figure 18 depicts the effect of engine capacity on the predicted probabilities in 2014 of injury and of fatal and serious injury crashes when PWR is included in the regression model. To add some context to this figure, it is useful to know that over the ten years, the average motorcycle size was between 600 and 700 cc, the maximum size was 9920 cc and the 90th percentile size was 1340 cc. Estimates of the magnitude of the effect per increase in engine size of one cubic centimetre follow using the *reduced* dataset, with continuous forms of engine capacity and power-to-weight ratios. In the injury crash analyses, engine size was analysed using a square root transformation.

- The odds ratio of an injury crash **decreased** by 2.9% (95% CI: 2.5-3.2, p<0.0001) for every 1 cc increase in engine capacity²⁷.
- The odds of a fatal and serious casualty crash **decreased** by 0.007% (95% CI 0.002-0.012, p=0.008) for every 1 cc increase in engine capacity (a 7% decrease for every 1000 cc increase in engine capacity).
- When Redbook type was added to the model, the odds **decrease** was estimated to be higher at 0.016% (95%CI: 0.009 to 0.023, p<0.0001).

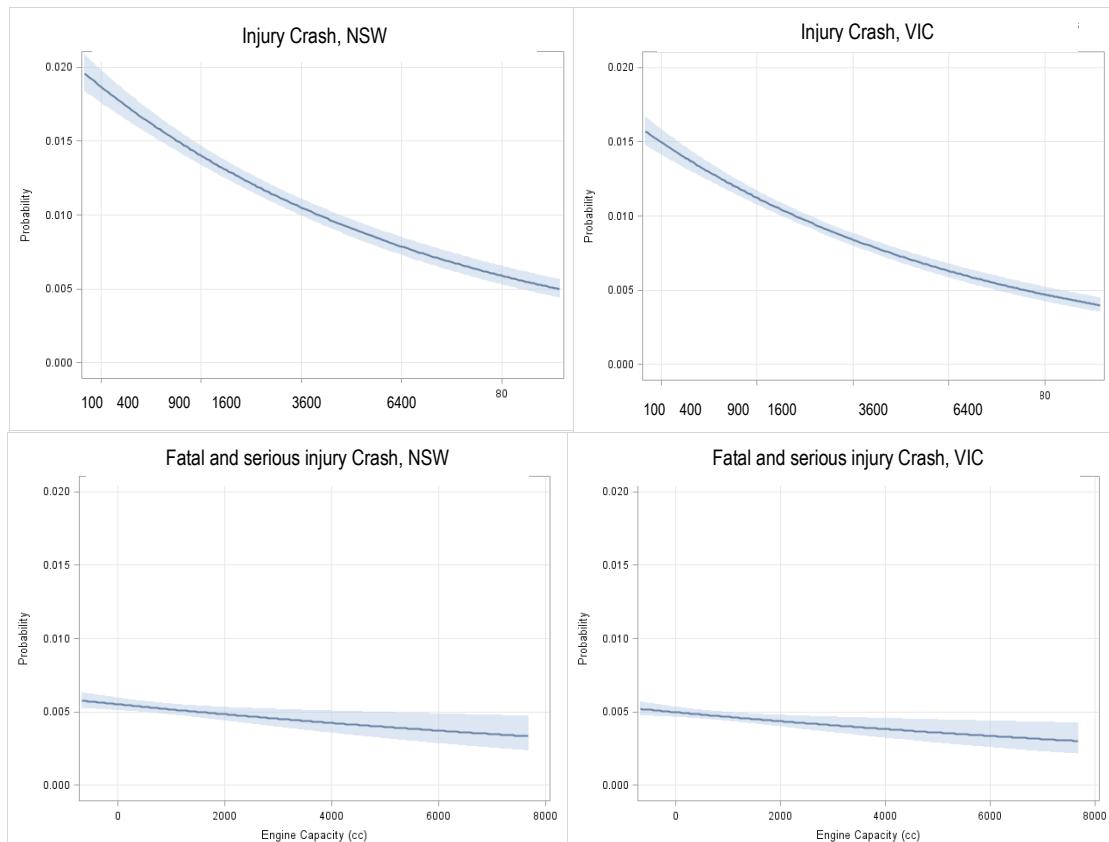


Figure 18 Predicted probability of an injury or fatal and serious injury crash by engine capacity for 2014 and each jurisdiction, at average power-to-weight ratios ($\alpha=0.05$)

The odds of a severe injury crash outcome adjusted for rider, motorcycle and crash attributes were found to increase by 0.026% (0.019-0.033, p<0.0001) for every 1 cc increase in engine capacity. This translated to a 2.6% increase for a 100cc change in engine capacity. Figure 19 depicts the trends by engine capacity for the predicted probabilities in 2014 for a more serious injury crash.

²⁷The estimate was the same, but with a wider confidence interval when Redbook Types were added to the model.

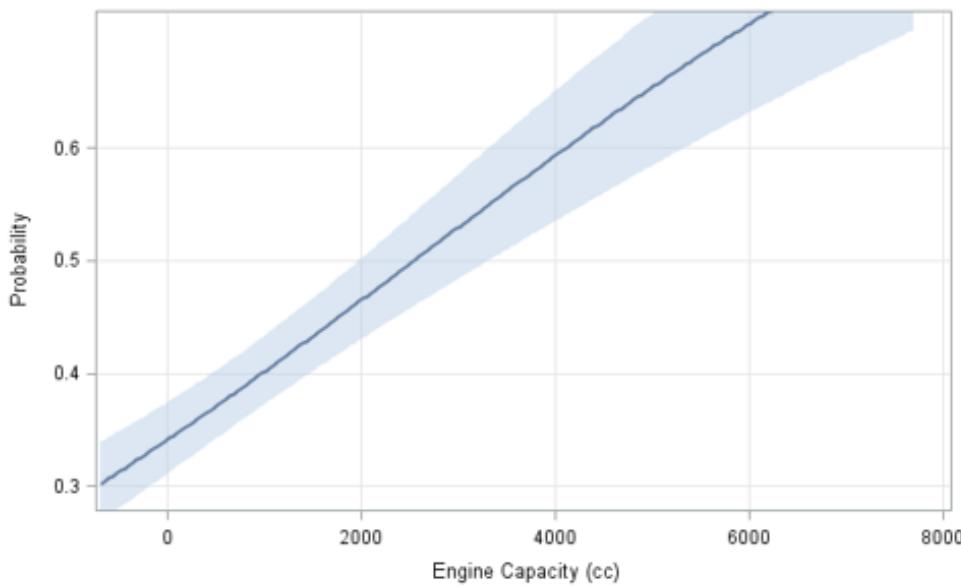


Figure 19 Predicted probability of a more severe injury crash outcome by engine capacity for metropolitan NSW in 2014 at reference covariate values and average engine power-to-weight ratio ($\alpha=0.05$). Note: Motorcycle engine capacities are typically range 50cc-1600cc

4.7 Effect of power-to-weight ratio

Rates of registration appeared similar and stable with respect to power-to-weight ratio categories from 2008 (Figure 20). Almost half of the registrations had a power-to-weight ratio in the 51-150 kW/t range. Over the ten years, the proportion of 151-350 kW/t registrations has declined slightly (from 30% to 24%) with complementary proportional rises in the 50 kW/t and under and the 350 kW/t and over motorcycle registrations. The 350+ group has almost doubled, increasing from 4% to 7%.

More than seventy percent of injury crashed and registered motorcycles in the 51-150 kW/t range and 100% of those in the 50 kW/t and under range, were learner approved (Figure 20). Within the 51-150 kW/t band the learner approved motorcycles had a higher rate of crashes, however, overall crash rates were higher in learner not approved motorcycles.

Injury crash rates were highest in the least represented group (350+), but fell over the period. Other groups tended to have a similar (fatal and serious) and stable injury crash rates (Figure 21).

The dip in crash rates between 2007 and 2012 is due to inflated NSW registrations.

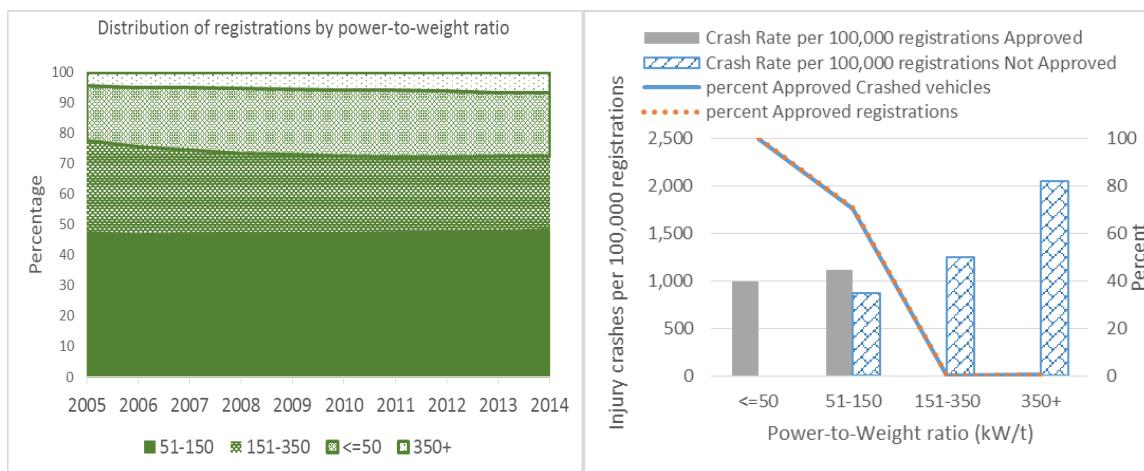


Figure 20 Stacked Distribution of power-to-weight ratio amongst RVSC matched registration data (2005 to 2014) and the Average Injury crash rates per 100,000 registrations by LAMS status and power-to-weight ratio

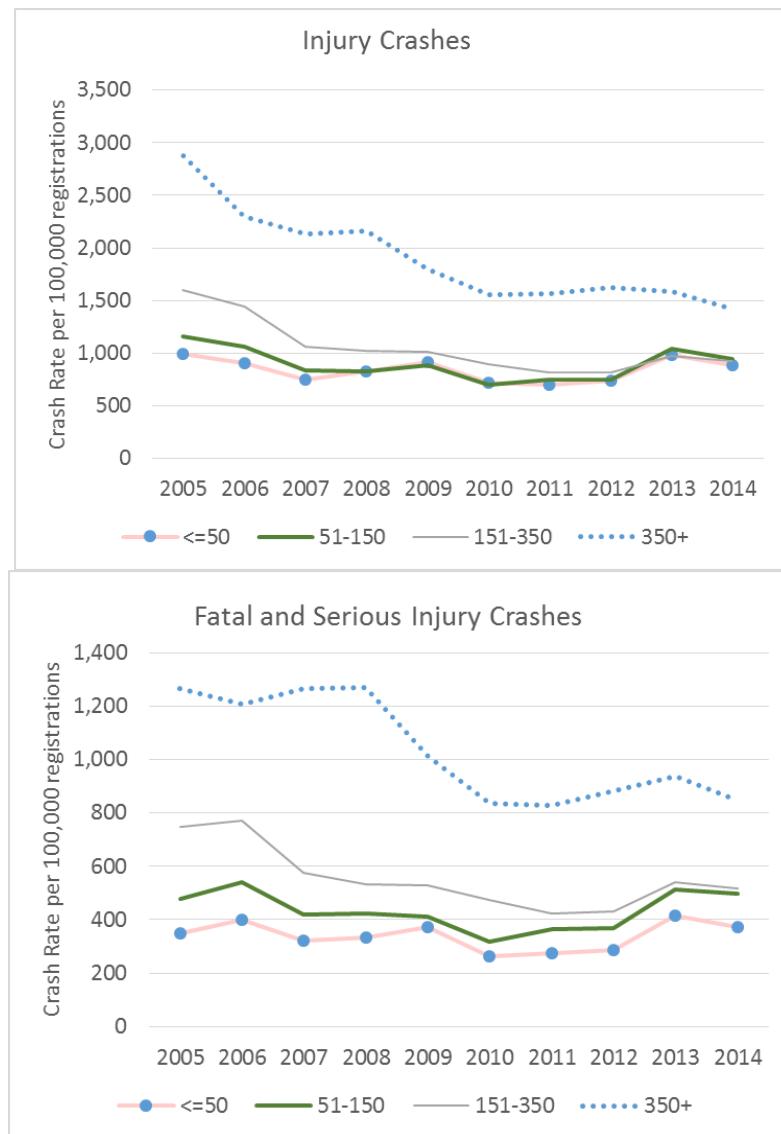


Figure 21 Injury and fatal and serious injury crash rates per 100,000 registrations by power-to-weight ratio categories (kW/t)

Power-to-weight ratios were not available to model when the *full* dataset was used in the *injury crash risk* and *crash severity* analyses. When modelled using the *reduced* dataset, and adjusted for jurisdiction, registration year and engine capacity, small and significant effects were estimated. Figure 22 depicts the trends by power-to-weight ratio for the predicted probabilities in 2014 for injury and fatal and serious injury crashes. To add some context to this figure, it is useful to know that over the ten years, the average motorcycle PWR was about 140 kW/t, the 90th percentile size was about 325 kW/t and the 99.99 percentile was 535 kW/t.

- The odds of an injury crash were estimated to increase by 2.01% (95% CI: 1.91-2.11, p<0.0001) for each 10 kW/t increase in the ratio. When Redbook type was included in the model, the estimate decreased to 0.87% (95% CI: 0.71-1.04, p<0.0001) for each 10 kW/t increase in the ratio.
- The odds of a fatal or serious injury crash were estimated to increase by 2.1% (95% CI: 1.98-2.25, p<0.0001) for each 10 kW/t increase in the ratio. When Redbook type was included in the model, the estimate decreased to 1.22% (95% CI: 1.00-1.44, p<0.0001) for each 10 kW/t increase in the ratio.

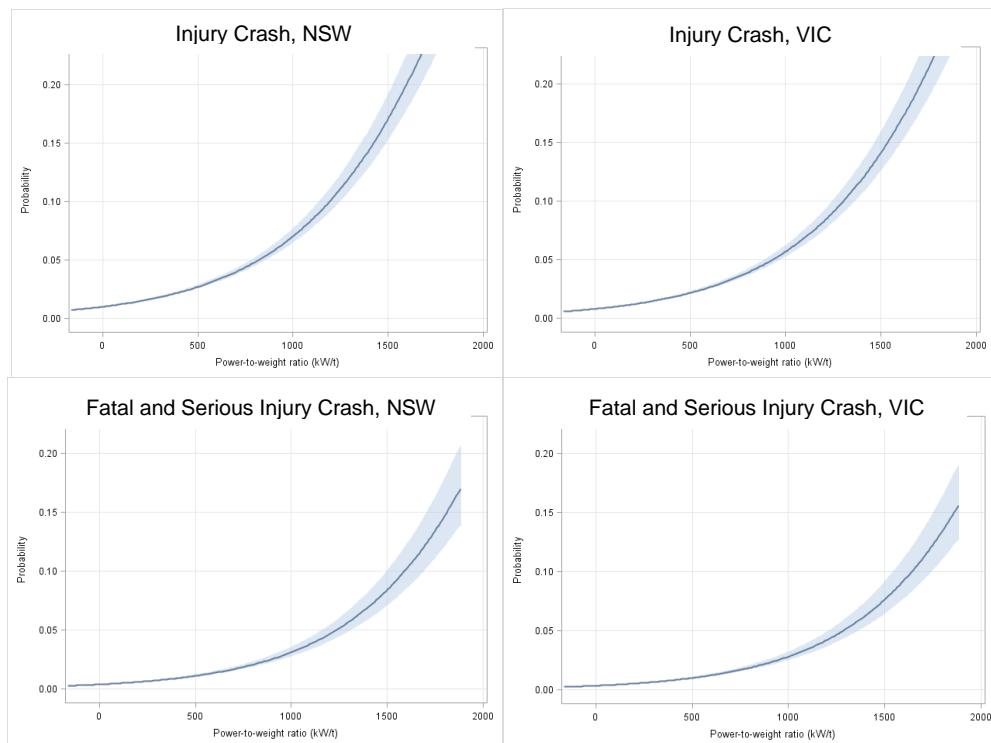


Figure 22 Predicted probability of an injury or fatal and serious injury crash by power-to-weight ratio for 2014 and each jurisdiction, at average engine capacity ($\alpha=0.05$)

After correction for temporal effects, motorcycle size, weight and power, Redbook types and significant crash covariates, the odds of a severe injury crash outcome were estimated to increase by only 0.049% (95% CI: 0.00 to 0.10 p= 0.0479) for every 10 kW/t increase in the ratio. This means that for each 10 kW/t increase in the ratio, the odds of an injury crash being fatal or serious increased on average by 0 %. Figure 23 depicts the trends by power-to-weight ratios for the predicted probabilities in 2014 for a more serious injury crash.

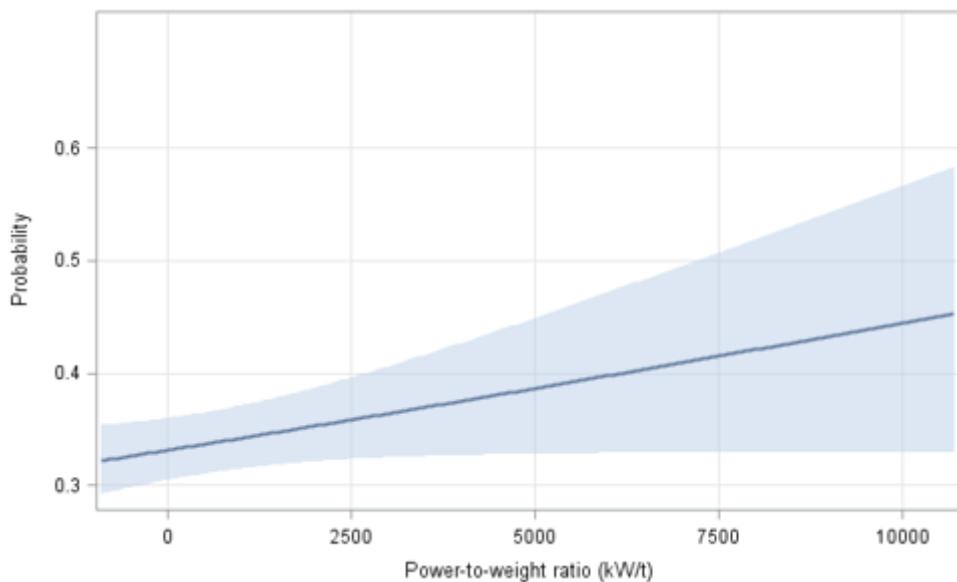


Figure 23 Predicted probability of more severe injury crash outcome by power-to-weight ratio (PWR) for metropolitan NSW in 2014 at reference covariate values and average engine capacity ($\alpha=0.05$)

Note: Motorcycle PWR are typically in the range 30-700 kW/t

4.8 Effect of LAMS status

Fifty-six percent (54%) of RVCS matched registered motorcycles were learner approved according to the current LAMS definition.



Figure 24 Injury and Severe Injury crash rates per 10,000 registrations by LAMS status and Redbook type

The Redbook types with the greatest proportion of learner approved registrations were Scooter, Off-road (all), Road, Enduro (off-road) and Chopper. Some of the most popular Redbook types had a low proportion of learner-approved motorcycles in NSW and VIC registrations. Over the period 2005 to 2014, the proportion of learner approved amongst injury-crashed motorcycles was similarly distributed amongst Redbook types (Figure 24).

Generally, fatal and serious injury and injury crash rates tended to be higher for learner NOT Approved motorcycles (Figure 25). Motorcycles of different LAMS status were found, over the ten years, to approach the same crash rates by 2013 (Figure 25). The dip in rates from 2007-2012 is due to inflated NSW registrations.

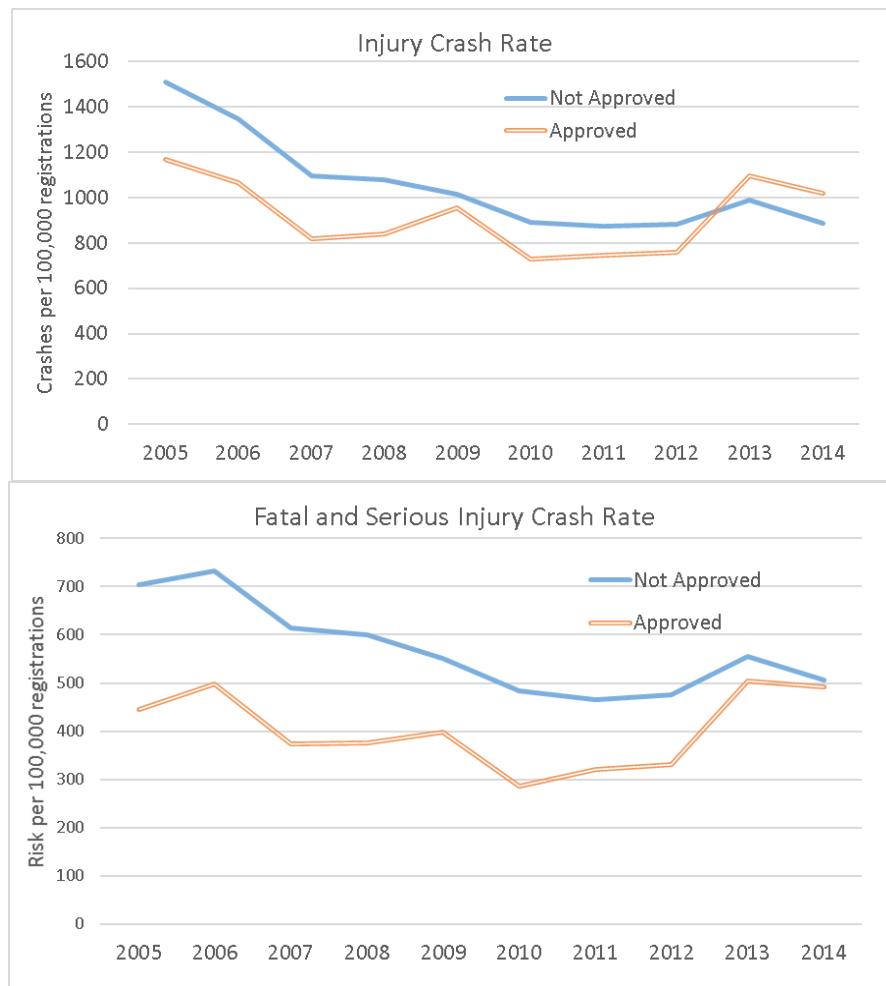


Figure 25 Injury and Severe Injury crash rates per 100,000 registrations by LAMS status

LAMS status was found (in sections 4.7 and 4.6) to be associated with both higher crash rates (51-150 kW/t) and lower crash rates (60-749cc). In this section, we have seen crash rates which were higher in learner approved motorcycles for many Redbook types (Sport, Touring, Classic, Naked, Enduro (off-road) and Cruiser), however, for other types, the rates were the same or lower, so clearly the influence of LAMS status is not straight forward. The relative difference is large for Cruisers, Sport, Enduro, Classic, Off-Road (all) and Motard.

LAMS status could not be modelled using regression of the *full* dataset, but when using the *reduced* dataset, significant effects were estimated. For learner approved motorcycle the odds of an injury crash were estimated to be 14% (95% CI: 12-17, p<0.0001) **lower** and the odds of a fatal or serious injury crash were estimated to be 30% (95% CI: 27-33, p<0.0001) **lower**.

LAMS status was not modelled in the crash severity logistic model, because of collinearity. When LAMS status was added, the engine size no longer contributed to the regression model in a significant way. Engine size with PWR were found to be better predictors of crash severity (Appendix 6).

4.9 Effect of Redbook type

Registrations were consistently highest for Sport, Cruiser and Off-road motorcycles (Figure 26). The next most popular amongst registrations were Scooter, Road and Touring motorcycles. Naked and Adventure, Enduro (off-road), Classic, Motard and Chopper were the least popular registered types over 2005 to 2014. Growth is apparent over 2005-2014 for Cruiser, Scooters, Naked, Adventure and Enduro (off-road) groups.

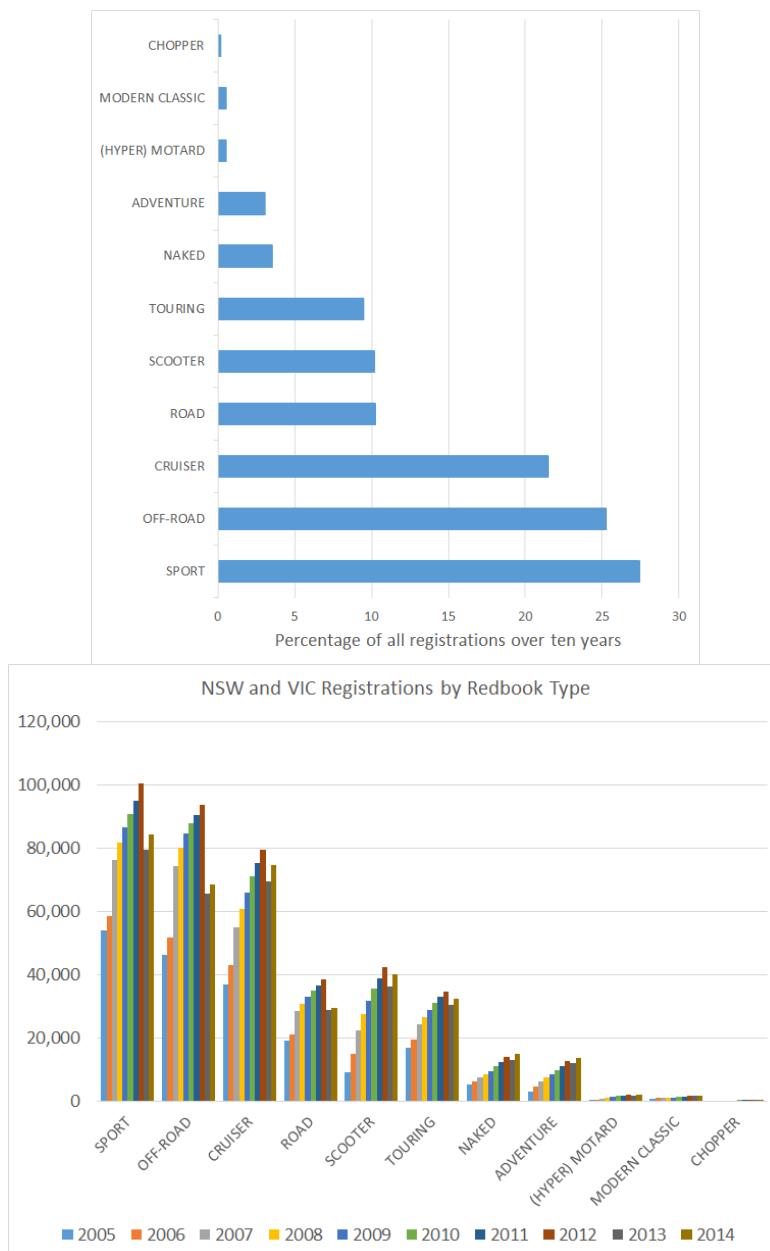


Figure 26 RVCS matched registration data (2005 to 2014) by Redbook type, percentage²⁸ of all and counts per registration year

The sharp rise in registrations for 2007 to 2012 for certain types (notably Off-Road) in Figure 26 RVCS matched registration data (2005 to 2014) by Redbook type, percentage of all and counts per registration year. Figure 26 is attributable to the inflated NSW registrations provided. The jurisdictional differences of Figure 26 have been presented in Appendix 8.6.

Crash rates per registration disaggregated by Redbook type have been divided into two charts (Figure 27): most popular and least popular. The crash rates of the less popular types were subject to much variation; Chopper crash rate variation in the earlier years was so great that the lower years have not been plotted. Again, the dip in rates between 2007 and 2012 is due to the inflated NSW registrations provided.

Injury crash rates were highest for Sport, Scooter and Naked types. Crash rates were obviously lowest for Off-road motorcycles (due to a likely over-estimated exposure on roads). For the most popular motorcycles, there were observable declines in crash rates over the period. Patterns were similar for fatal and serious crash risk.

²⁸As motorcycle models may have been classified into more than one Redbook Type, percentages may add up to more than 100.

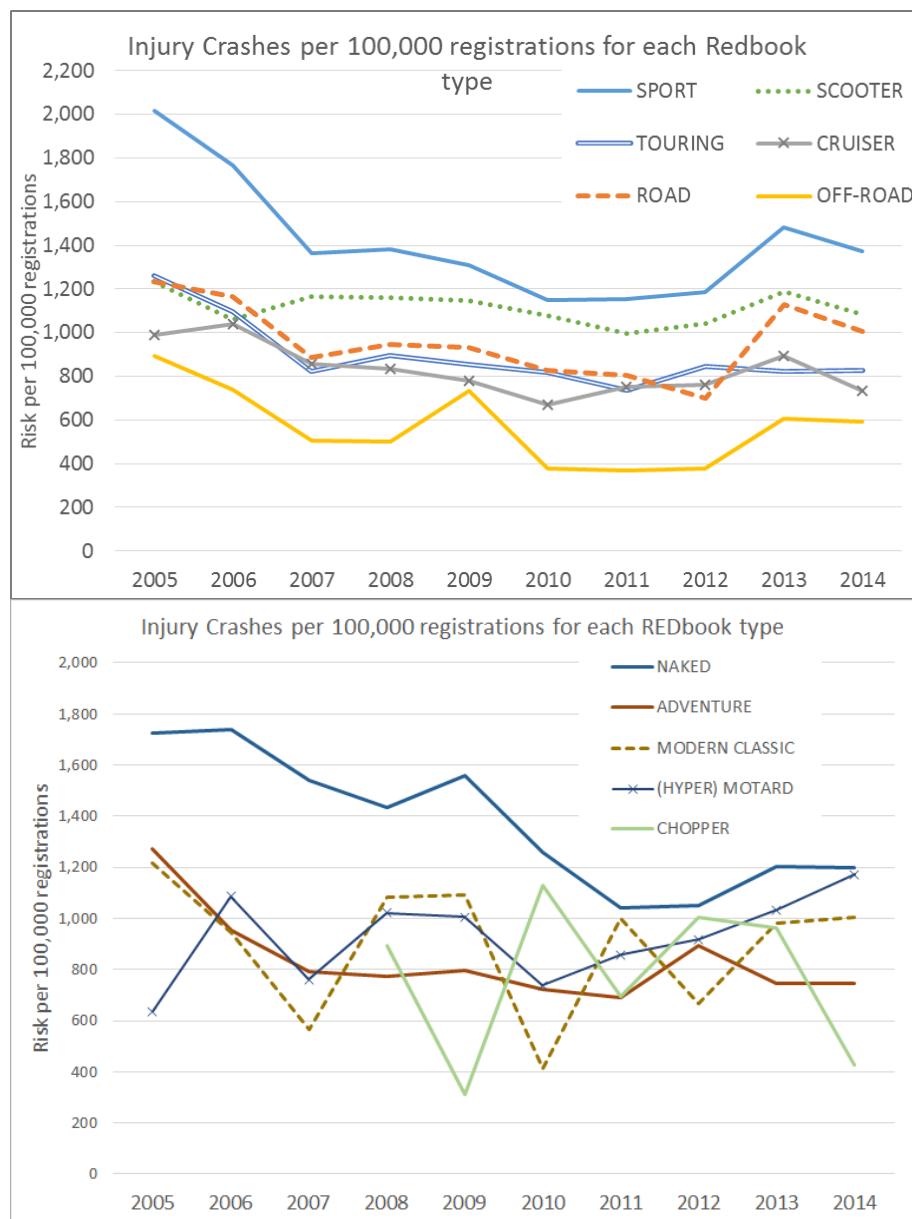


Figure 27 Injury crash rates per 100,000 registrations by Redbook type (2005 to 2014)

Injury crash rates did not decrease for Scooters at the same rate as for 60cc engine size motorcycles. This is because Scooters included engine sizes of 100 and 150 cc as well as the under 60cc engines, so even though 60cc crash rates were steeply declining, it was feasible for Scooters to have a less noticeable decrease in crash rates over the period.

Figure 28, Figure 29 and Figure 30 demonstrate the injury crash risks associated with different Redbook types. These charts depict model estimates where Redbook type is a categorised variable and Off-Road as the chosen reference category. Off-road was chosen because of its low crash rate and high proportion amongst registrations. This will give the odds ratio estimates stability and allow ranking of all other motorcycle types.²⁹ Each chart clearly presents the hierarchy of types from highest to lowest risk.

When compared against the Off-Road (excl. Enduro) category, Touring, Road and Cruiser motorcycles had odds ratio estimates of an injury crash that were 62-72% greater and Enduro, Sport and Naked had estimates that were 1.9 to 2.4 times the odds of an injury crash (Figure 28).

²⁹Alas, in creating a categorical variable, the category 'Adventure' was lost. When a single Redbook Type was assigned to each case (where cases had multiple assigned Redbook types) a hierarchy was used which was based on the strength of significance of the odds ratios for the alternative injury crash model (Appendix 8.5).

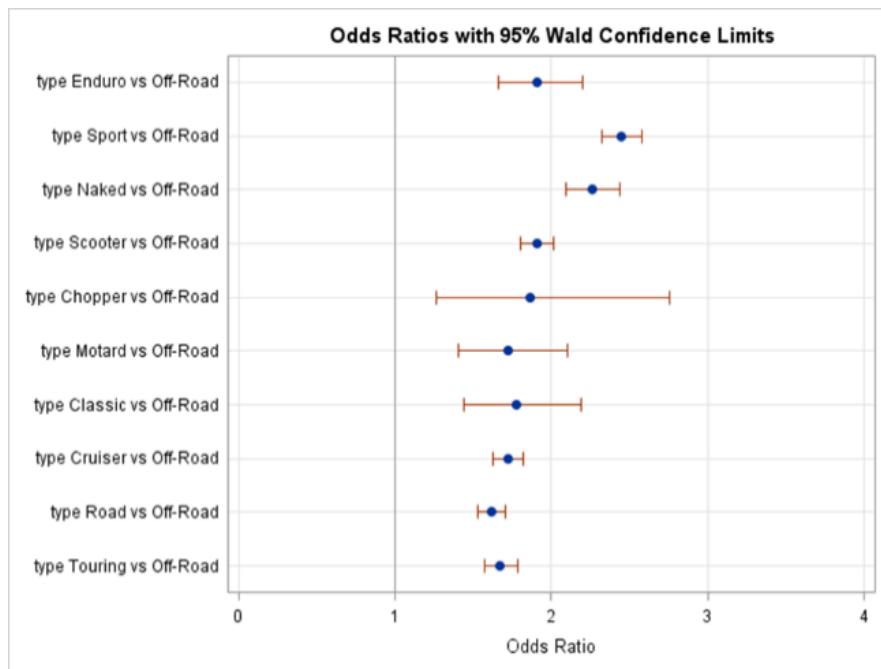


Figure 28 Odds of an injury crash by Redbook type (2005 to 2014)

When compared against the Off-Road (excl. Enduro) category, Touring, Road and Motard motorcycles had estimated 43-54% greater odds of a fatal or serious injury crash and Enduro, Sport and Naked had an estimated 2.0 to 2.3 times the odds of a fatal or serious injury crash (Figure 29). Note: Enduro is an off-road subcategory.

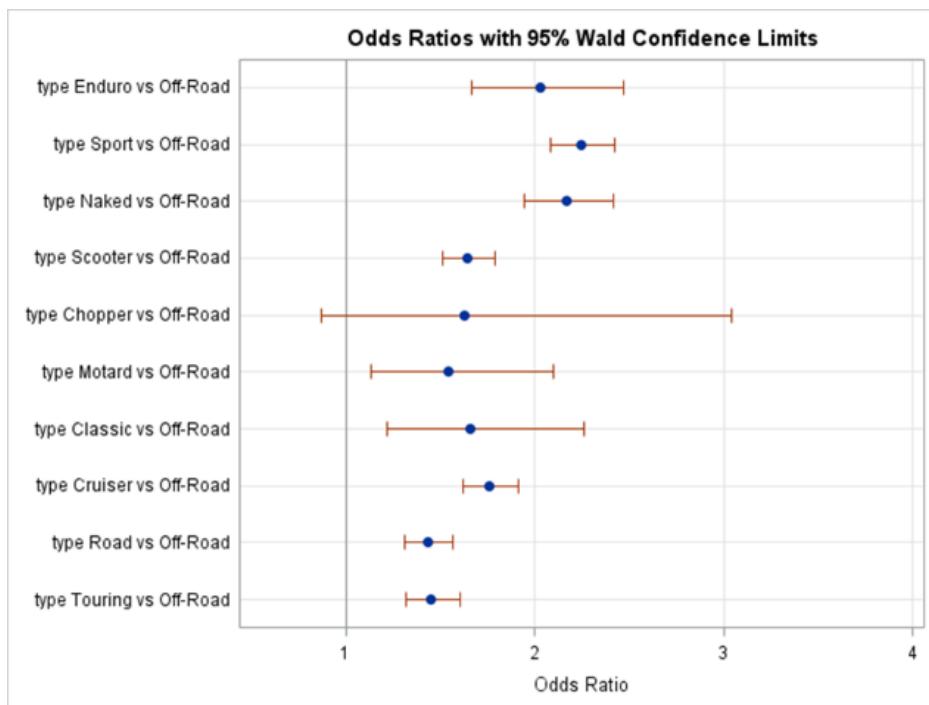


Figure 29 Odds of a fatal or serious injury crash by Redbook type (2005 to 2014)

When compared against the Off-Road category, all types had lower odds of a severe injury crash outcome. The greatest difference was for Touring, Scooters and Road motorcycles which had 19-25% lower odds of a more serious injury

crash. All other types had reduced odds estimates that fell between 7 and 12% (Figure 30). Note: Enduro is an off-road subcategory.

The alternative modelling of Redbook type, using references against all other types is presented in Appendix 8.5

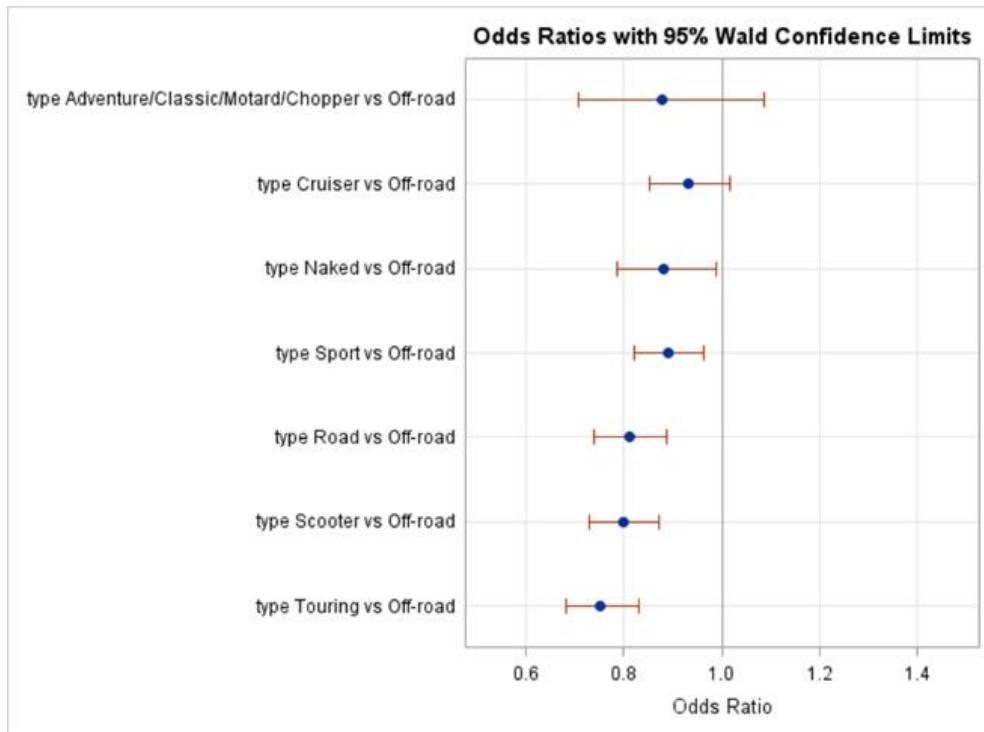


Figure 30 Odds of a severe injury crash outcome by Redbook type (2005 to 2014)

4.10 Effect of engine capacity and Redbook type

After adjusting for registration year, jurisdiction and power-to-weight ratio, engine capacity was found to be *negatively* associated with injury crash risk, (and barely associated in a negative fashion with fatal and serious injury risk), whilst *positively* associated with the risk of a more serious crash. When Redbook type was added to the crash risk models, the negative association was the same magnitude for injury crash risk but it increased in magnitude for fatal and serious injury crash risk. Because of these relationships, the interacting relationship of engine capacity and Redbook type was explored.

An interaction term was added to the *reduced* data model (iv) which used a single categorical variable to represent motorcycle type. From this analysis, the sensitivity of crash risk to engine size for each type of motorcycle could be determined. Those types that were sensitive had a significant interaction term. For each type with a significant interaction term, the crash risk associated with engine size could be estimated.

Adding the interaction, made the odds of an (fatal and serious) injury crash have a positive association with engine capacity for Road motorcycles; this type was used as the reference value. For each increase in the engine capacity of Road motorcycles by 1 cc, the injury crash odds increased by 1.5% (95%CI: 0.3-2.6, p=0.012) and the fatal and serious injury crash odds increased by 0.03 % (95%CI: 0.01-0.05, p=0.011).

The effect of engine capacity on the odds of a more severe injury crash outcome was not sensitive to Redbook type. (There were no significant interactions and the addition of interaction term to model made no significant difference to the model).

For both injury and fatal and serious injury crash risk analyses, Scooter, Chopper and Classic produced non-significant interactions; the latter two, due to relatively small sample sizes, the former most likely due to the narrow range and small engine capacities of this type. In addition, for the injury analysis, the interaction with Motard was also not significant.

Of the significant interactions, Enduro (off-road), Sport, Naked, Cruiser and Touring were associated with risk *reductions* and Motard, Road and Off-road were associated with risk *increases*. Table 9 and Table 10 show that Off-road motorcycles were the type most sensitive type to crash risk increases with increasing engine capacity. Road types

showed a much lower sensitivity with only a small magnitude of a 1.5% increase in odds of an injury crash with each 1 cc increase in engine capacity. Enduro motorcycles were the most sensitive to crash risk *decreases* with increasing engine capacity, which is surprising given the opposite finding for other off-road categories. Within the two tables, associated increases are shown as a *negative* odds ratio reduction.

TABLE 9 INJURY CRASH ODDS RATIO REDUCTIONS ASSOCIATED WITH ENGINE CAPACITY BY TYPE

Type	% Odds Ratio reduction for each 1cc rise	95% Confidence Interval	Significance of interaction coefficient
All types	2.9	(2.4,3.4)	
Enduro	14.6	(7.7, 21.1)	<0.0001
Sport	6.5	(4.9, 8.1)	<0.0001
Naked	8.5	(5.4, 10.8)	<0.0001
Touring	6.1	(3.9, 8.3)	<0.0001
Cruiser	4.2	(2.5, 5.8)	<0.0001
Road	-1.5	(-3, -2.6)	0.012
Off-Road	-10.3	(-7.7, -12.9)	<0.0001

Remembering, that engine capacity essentially had no contribution to fatal and serious crash risk, it is not surprising that the significant interactions for fatal and serious crash odds ratios by Redbook type, for the most part, equate to estimates of <1% change in the odds of a fatal or serious injury crash with each 10 cc increase in engine capacity. There were three exceptions of estimated odds ratios with greater magnitudes. These are bolded in *Table 10*. When considering the interaction of type and engine capacity, there were no sizeable relationships found, of significance, between engine capacity and fatal and serious crash risk for any Redbook types with the exception of:

- Enduro which had a much higher than average fatal and serious injury risk *reduction* associated with an increase of 1cc in engine capacity;
- Motard and Off-Road, each of which were estimated to have an *increase* in the odds of a fatal and serious injury crash risk associated with a 1 cc rise in engine capacity.

TABLE 10 SERIOUS AND FATAL CRASH ODDS RATIO REDUCTIONS ASSOCIATED WITH ENGINE CAPACITY BY TYPE

Type	% Odds Ratio reduction for each 1cc rise	95% Confidence Interval	Significance of interaction coefficient
All types	0.016	(0.009,0.023)	
Enduro	0.17	(0.05,0.29)	0.001
Sport	0.05	(0.02,0.08)	<0.0001
Naked	0.04	(0.00,0.09)	0.0003
Touring	0.03	(0.00,0.07)	0.0001
Cruiser	0.02	(0.00,0.05)	<0.0001
Road	-0.03	(-0.01,-0.05)	0.011
Motard	-0.12	(-0.02,-0.22)	0.058
Off-Road	-0.12	(-0.08,-0.16)	<0.0001

4.11 Effect of rider attributes

Rider attributes found in crash data were used as predictors of the odds of a severe injury crash outcome. The actual percentage of crashes that made up the categories of rider sex, age, helmet wearing and licensing were fairly stable over the 2005-2014 period. Figure 31 shows small steady rises in the proportion of older riders (60+) and female riders and recent decreases in the proportion not wearing a helmet and the proportion of probationary riders. The average age of an injury-crashed rider has increased from 36 to 42 over the ten years.

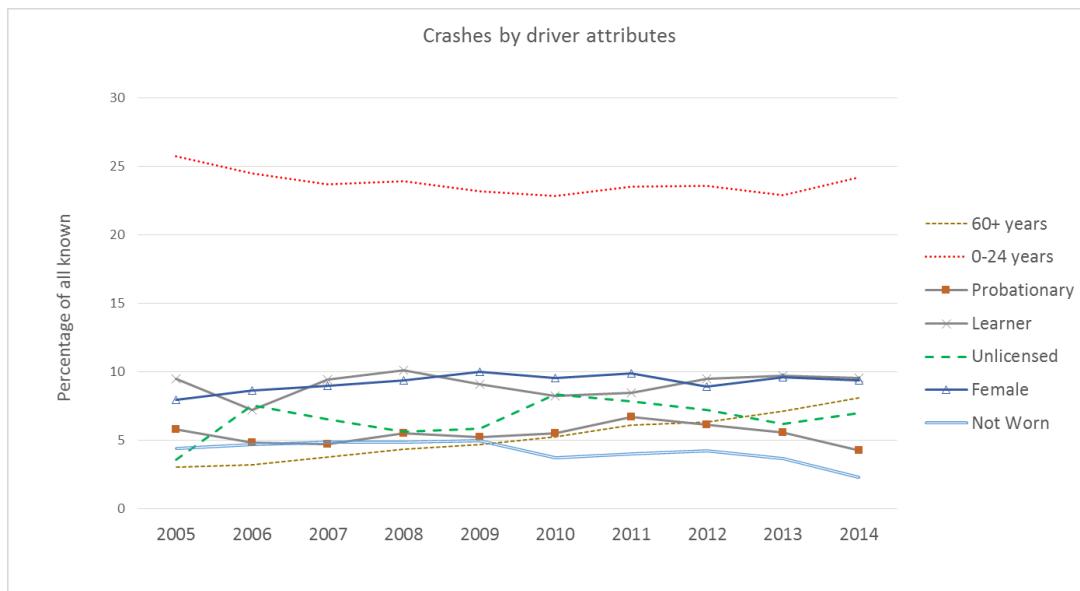


Figure 31 Proportion of crashes by rider attribute categories³⁰

Proportions of the various rider attributes within injury crashes were fairly stable from 2008.

- About 70% of riders were aged between 25 and 59 and 23% were younger³¹, however compared to these two groups there was growth in older rider crashes. The proportion of crashed riders aged 60 years and over more than doubled in the 10 years.
- About 80% of crashed riders had their full licence and about 15% had P or L status, however compared to these two groups, the proportion of unlicensed riders almost doubled in the ten years (SA, WA and VIC data only).
- The proportion of crash records of wearing helmets has grown from 95 to 98% over the ten years.
- The proportion of crashed rider injury by severity is not plotted here: fatalities are stable at 3%, seriously injured averages at 45% and on average 52% of riders had minor injuries.
- The proportion of female riders in injury crashes increased 2% units over the period.

³⁰Missing data was not used to create percentages.

³¹7% were aged 60 and older.

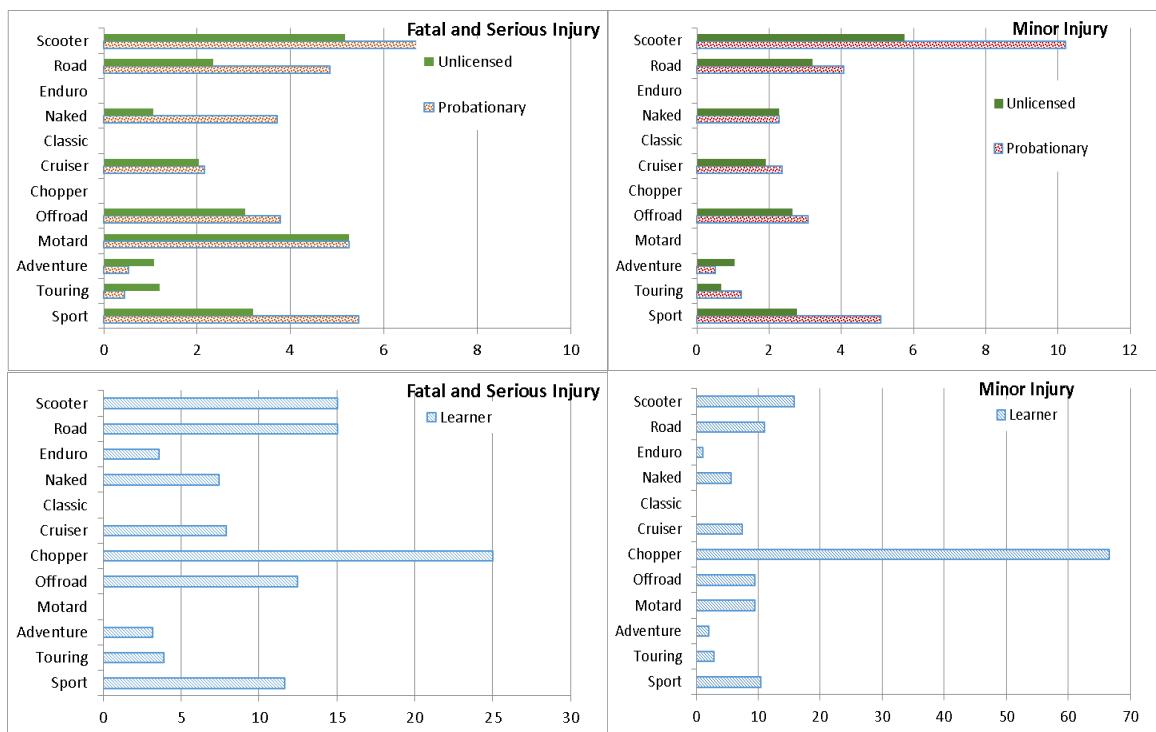


Figure 32 Proportion of crashes with licence type within a Redbook type by crash injury category³²: over 2004-2015

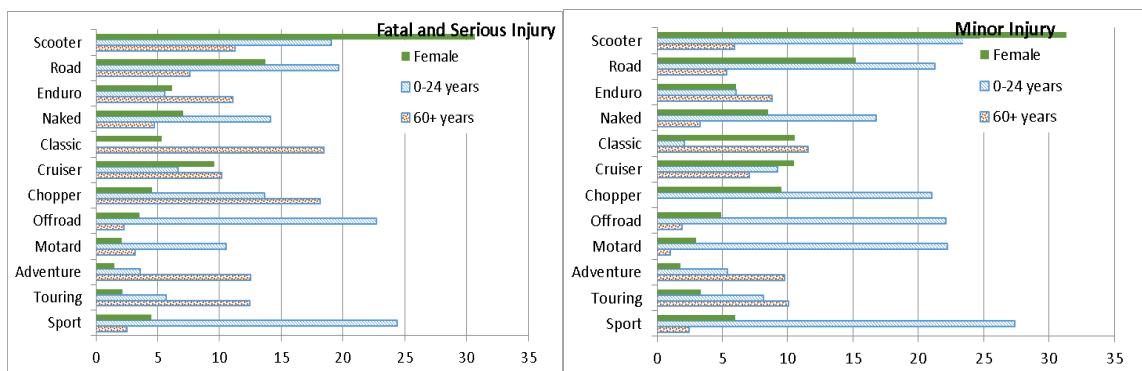


Figure 33 Proportion of crashes with female riders and proportion of crashes of rider age groups within a Redbook type by crash injury category³³: over 2004-2015

Rider attributes that were over-represented within Redbook types in fatal and serious or minor injury crashes are presented in Figure 32 and Figure 33. Chopper motorcycles represented less than 0.1% of both minor and fatal and serious injury crashes, so the large percentages of learner rider crashes in this group must be interpreted with caution.

- Learner riders were over represented for:
 - minor injury crashes in Chopper and Scooters;
 - fatal and serious injury crashes involving Chopper, Scooters and Road.
- Probationary riders were over represented for:
 - minor injury crashes in Road, Off-road, Sport and Scooters;
 - fatal and serious injury crashes in Road, Motard, Sport and Scooters.
- Unlicensed riders were over represented for:
 - minor injury crashes in Road, Off-road, Sport and Scooters;

³²Missing/unknown data were not included in the totals (denominators) when creating these percentages.

³³Missing/unknown data were not included in the totals (denominators) when creating these percentages.

- fatal and serious injury crashes in Off-Road, Motard, Sport and Scooters.
- Older (60+) riders were over represented for:
 - minor injury crashes in Classic, Adventure and Touring;
 - fatal and serious injury crashes in Classic and Choppers.
- Younger (<25) riders were over represented for:
 - minor injury crashes in Sport, Scooter, Off-road and Motard;
 - fatal and serious injury crashes in Sport, Scooter, Road and Off-road.
- Female riders were over represented for:
 - minor injury crashes in Scooter and Road;
 - fatal and serious injury crashes in Scooter, Road and Cruiser.

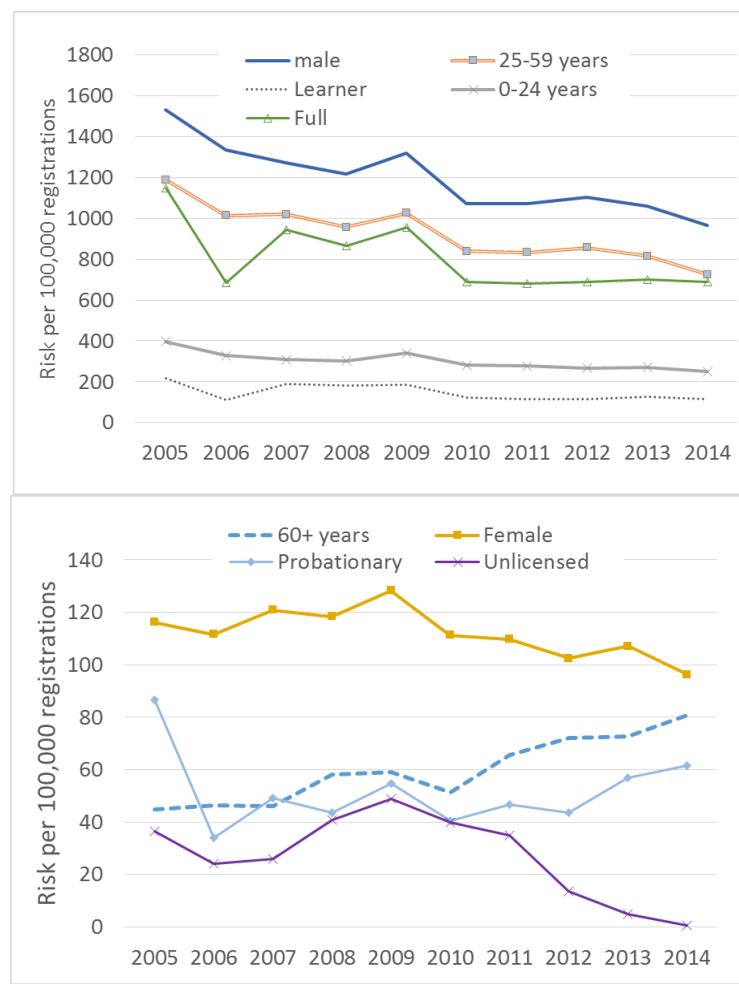


Figure 34 Injury Crash rates per 100,000 registrations for rider attributes by crash year³⁴

When injury crashes were expressed as a rate per all motorcycle registrations for the year (for NSW and Victorian data)³⁵, some interesting trends appeared (Figure 34). There were clearly increasing rates over the period for riders aged 60 and over, and for probationary licence holders. Over the 2005-2014 period, injury crash rates (per 100,000 motorcycle registrations) have almost doubled for 60+ riders.

Female and older riders tended to crashing younger motorcycles (Figure 35).

³⁴Registration data could not be disaggregated by crash nor by rider attributes. ABS adjusted registrations are used in the denominator. Licensing categories are based on VIC data only.

³⁵Licence information is not available in NSW data so crash rates by licence information is based only on Victorian data.

Male riders tended to crashing older motorcycles (Figure 35).

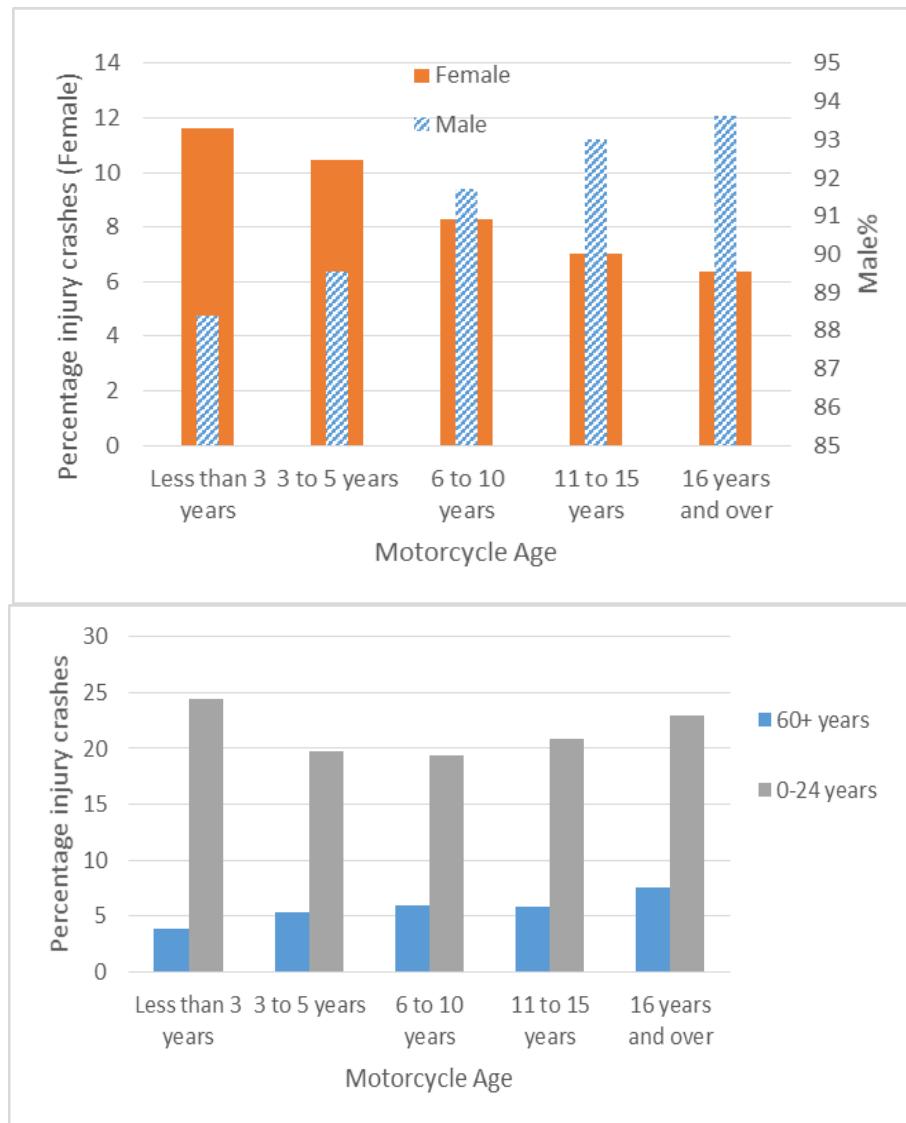


Figure 35 Average 10 year injury crash proportions for motorcycle age groups by rider sex and age

With the exception of Off-road motorcycles, which by definition should have had lower crash rates (on roads), crash rates by motorcycle type were more evenly distributed for 25-59 year old riders (Figure 36) than for other age groups.

- Classic motorcycles were crashed more often by older riders and less often by younger riders.
- Sport motorcycles were most frequently crashed by riders under 25 and least frequently crashed by older riders.

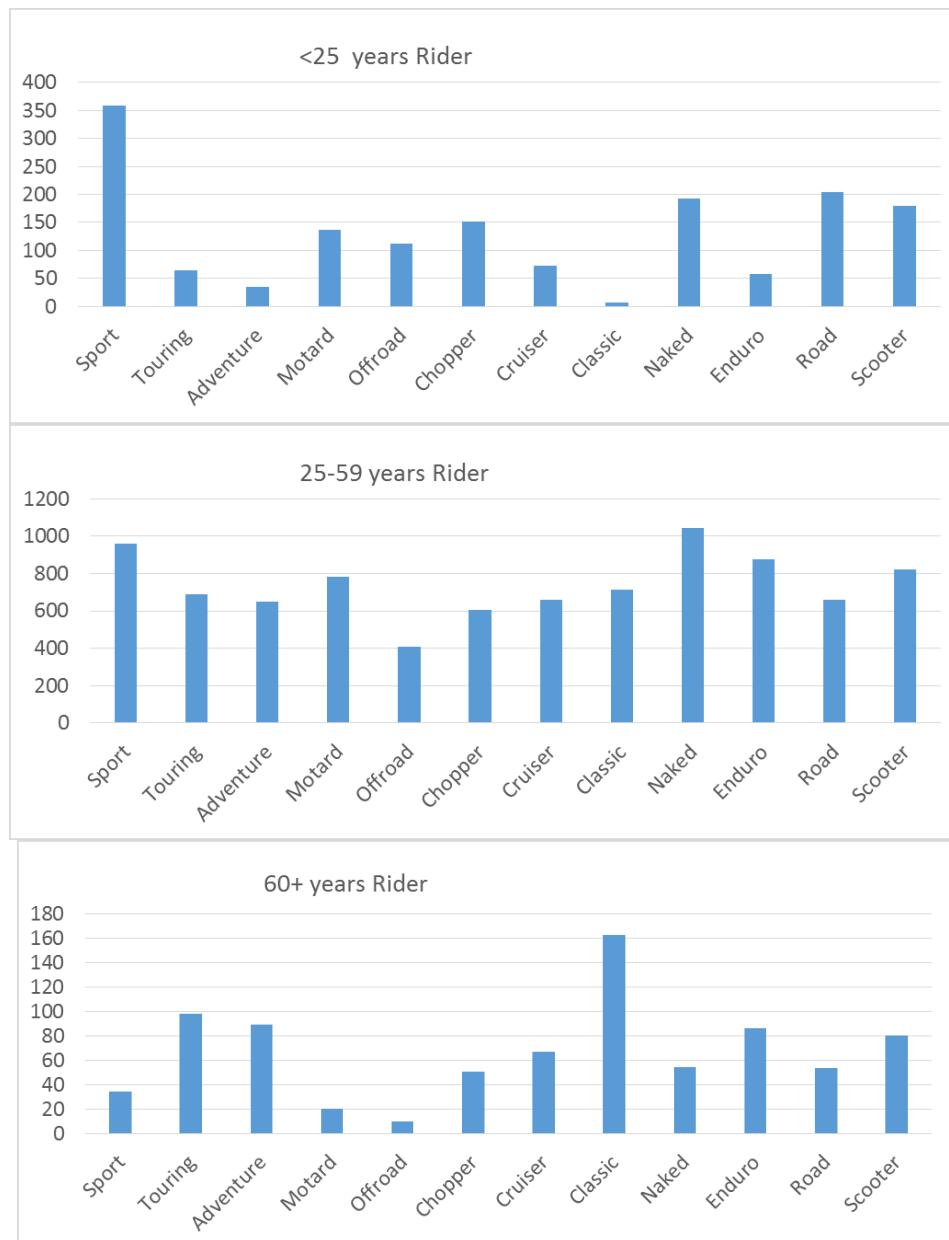


Figure 36 Average 10-year injury crash rates per 100,000 registrations of same Redbook type by Rider age³⁶

³⁶Denominators are registrations by Redbook type.

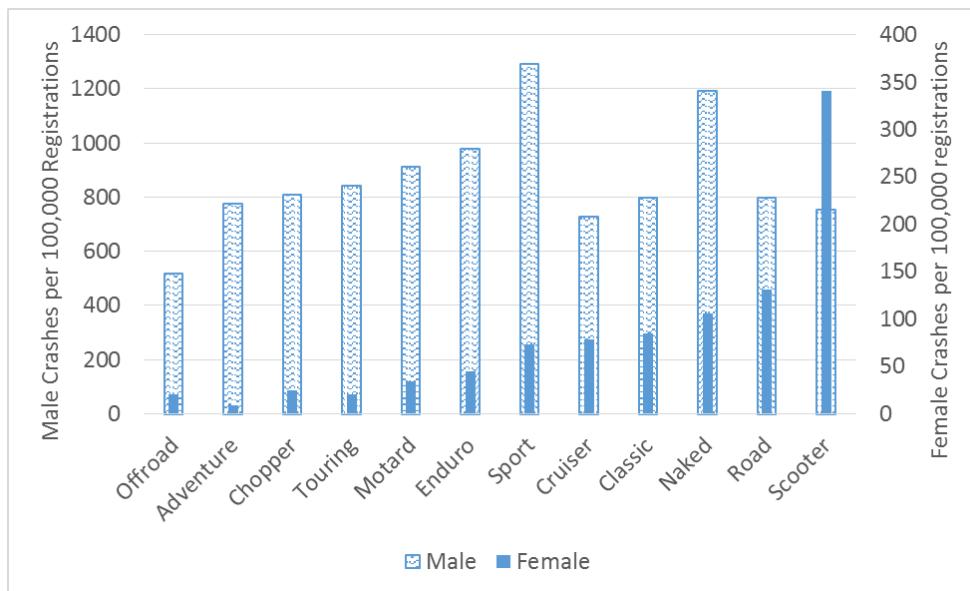


Figure 37 Average 10-year injury crash rates per 100,000 registrations of Redbook type by Rider sex³⁷

Female riders were over-represented in injury crash rates by Scooters and Road types and males by Sport and Naked types (Figure 37).

Riders 25 years of age and over experienced injury crashes at up to half the rates if they were in learner-approved motorcycles (Figure 38). The finding of rising injury crash rate ratios of *Approved to Not Approved* motorcycles for riders under 25 of Figure 38 brings clarity to the relationship of diminishing differences between *Approved* and *Not Approved* injury crash rates seen in Figure 25. The relative crash rate ratio for riders aged under 25 is clearly confounded by rider experience or age (or both).

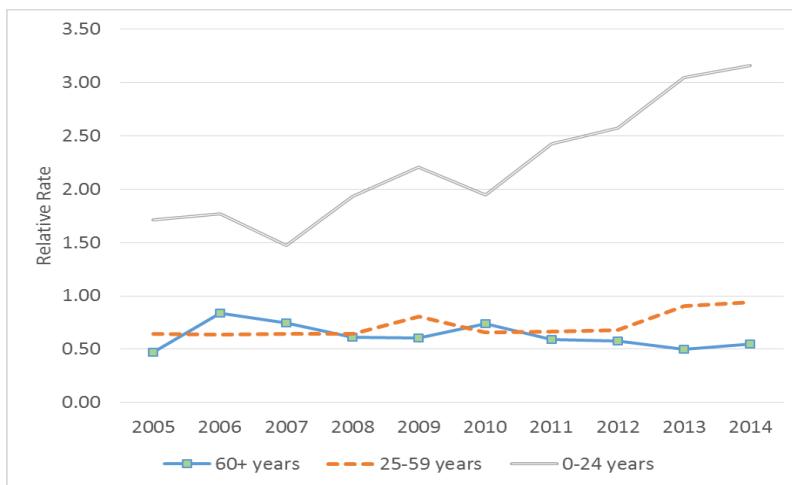


Figure 38 LAMS Ratio of rider age grouped injury crash rates per registration: Approved to Not Approved³⁸

When adjusted for jurisdiction, registration year, rider and motorcycle attributes and crash variables, the odds of a severe injury crash outcome for probationary riders were not found to be different from full licence riders. However, the odds of severe injury crash outcome were relatively greater for learner and unlicensed riders (Figure 39) than for riders on their full licence.

- Learner riders had 12% higher odds of a more serious crash than riders on their full licence (95% CI: 1-25, p=0.035).

³⁷Denominators are registrations by Redbook type.

³⁸Denominators are registrations by LAMS approval status.

- Unlicensed riders had 25% higher odds of a more serious crash than riders on their full licence (95% CI: 3-51, p=0.02).

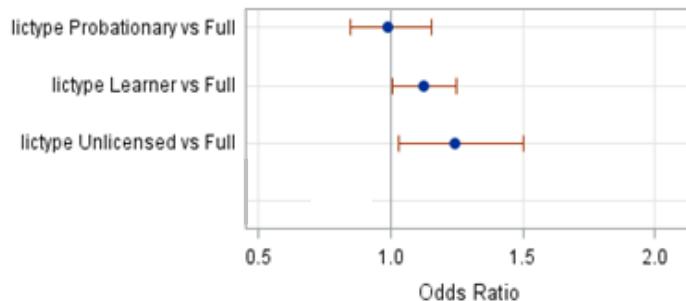


Figure 39 Odds ratio of a severe injury crash outcome by rider licence type

When adjusted for jurisdiction, registration year, rider and motorcycle attributes and crash variables, the odds of a severe injury crash outcome were not found to be affected by rider sex, however, the odds of a severe injury crash outcome increased with rider age and were higher when a helmet was *not* being worn (Figure 40).

- Riders *not* wearing a helmet had 72% higher odds of a severe injury crash outcome than helmet wearers (95% CI: 42-109, p<0.0001).
- Riders under 25 years of age had 11% lower odds of a severe injury crash outcome than riders aged 25-59 (95% CI: 6-16, p<0.0001).
- Riders 60 years and over had 39% higher odds of a severe injury crash outcome than riders aged 25-59 (95% CI: 27-53, p<0.0001).

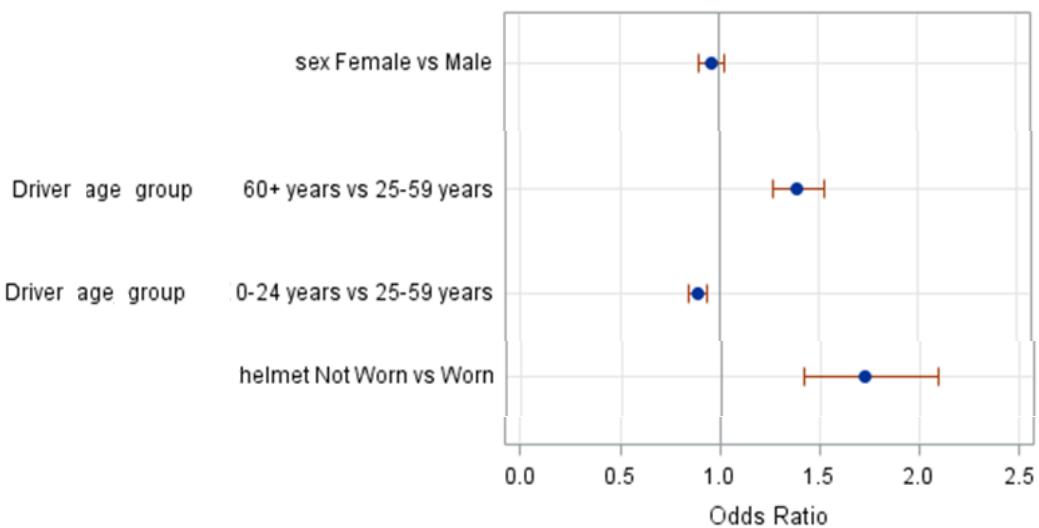


Figure 40 Odds Ratio of a severe injury crash outcome by rider age, sex and helmet wearing status

4.12 Effect of crash location

Crash attributes found in crash data were used as predictors of the odds of a severe injury crash outcome. The percentage of crashes that made up categories of location (metropolitan, rural and remote, intersection: yes or no/unknown, curved road: yes or no/unknown and speed zone: 50 and under, 51-79 and 80+), were actually very stable over the 2005-2014 period (Figure 41).

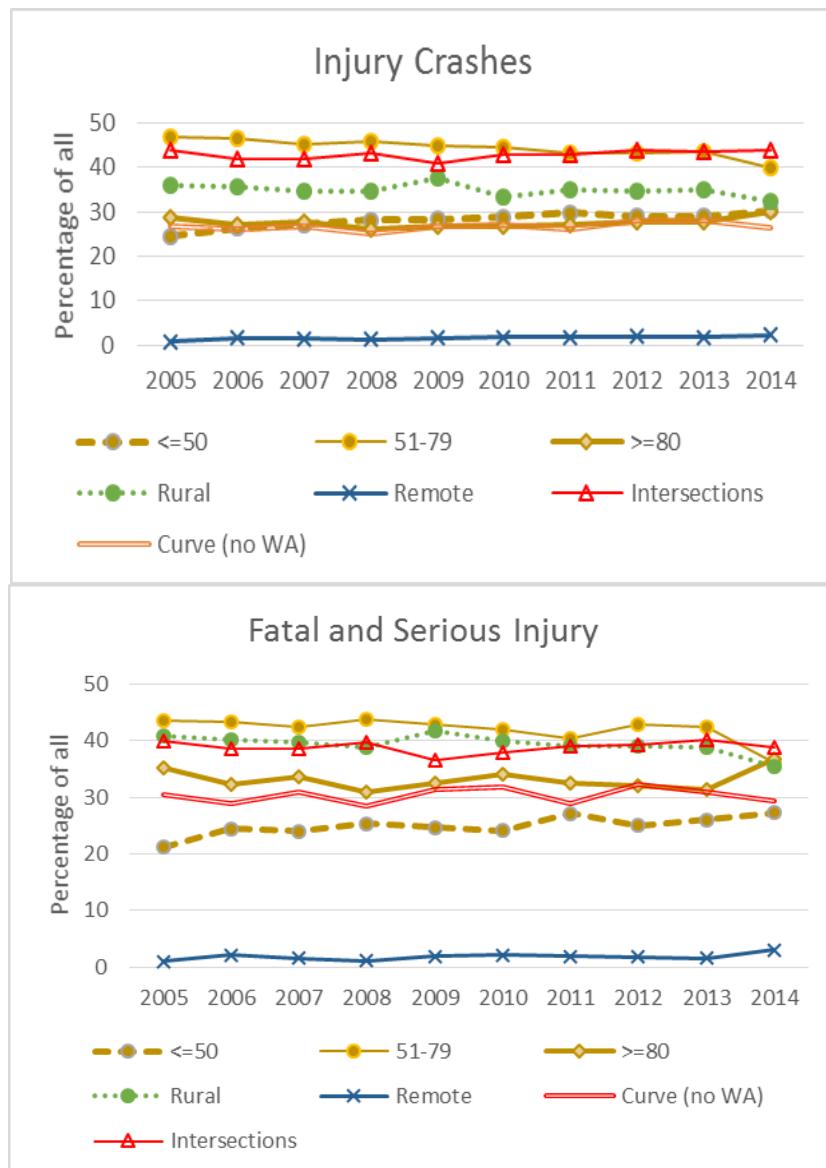


Figure 41 Proportion of injury crashes by crash location

- Amongst speed zones, crashes in zones 60 and 70 km/hr (51-79) were the most prevalent (making up almost half in 2005), but have decreased slightly in proportion over time relative to lower speed zone crashes.
- Injury crashes were almost twice as likely to be metropolitan, with the proportion metropolitan increasing slightly over time. The proportion rural was higher for fatal and serious injury than for injury crashes.

For all crash locations, no injury crash rates per registration were observed as increasing (Figure 42).

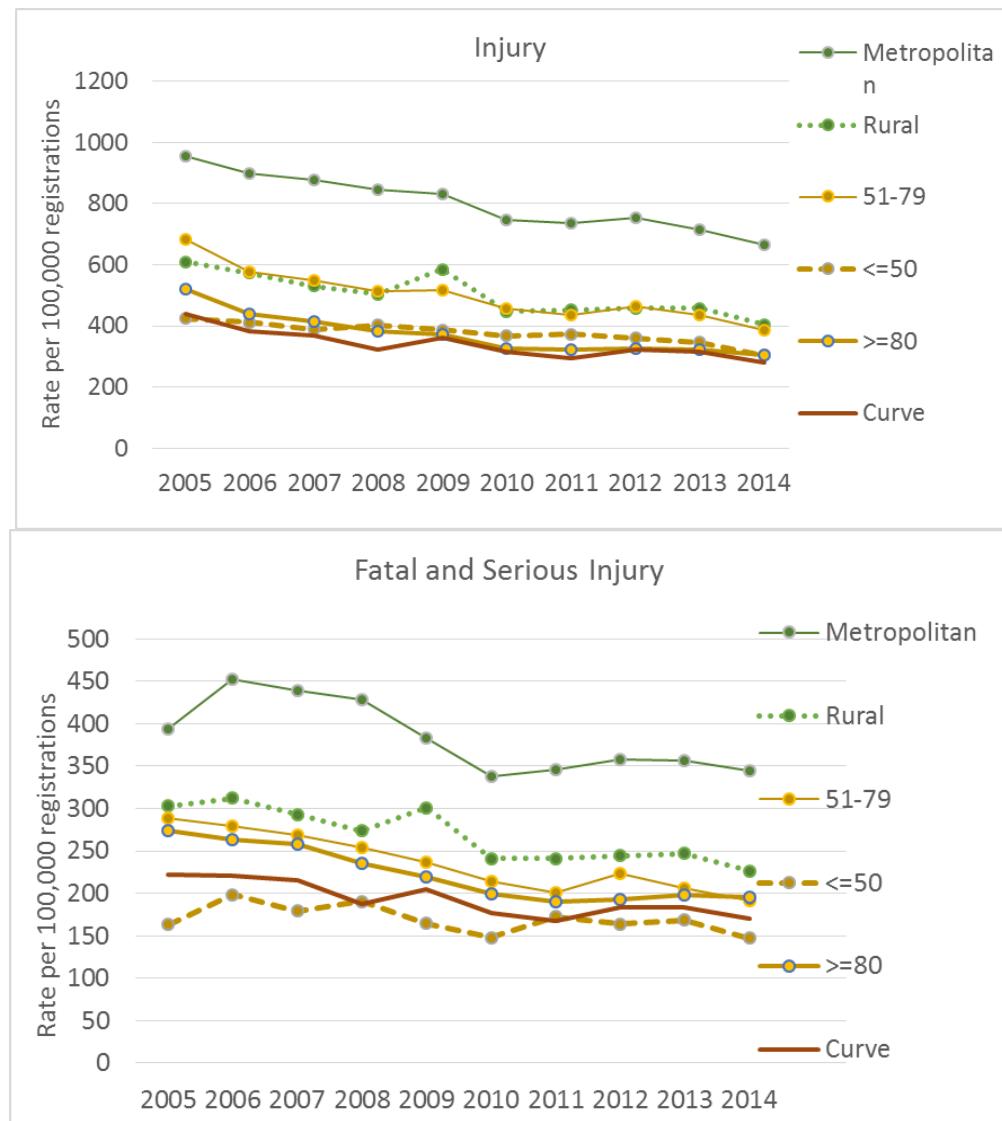


Figure 42 Crash rates per 100,000 registrations for crash location by crash year³⁹

By Redbook type (Figure 43):

- Scooters, Sport and Naked types faced the highest injury crash rates in metropolitan locations and intersections;
- the next highest injury crash rates at an intersection were for Road and Chopper types;
- Enduro types, followed by Adventure, Classic and Touring types, presented the highest rural injury crash rates;
- Scooters had a low rural injury crash rate.

³⁹Registrations could not be disaggregated into crash location groups. Exposure is ABS adjusted registration counts.

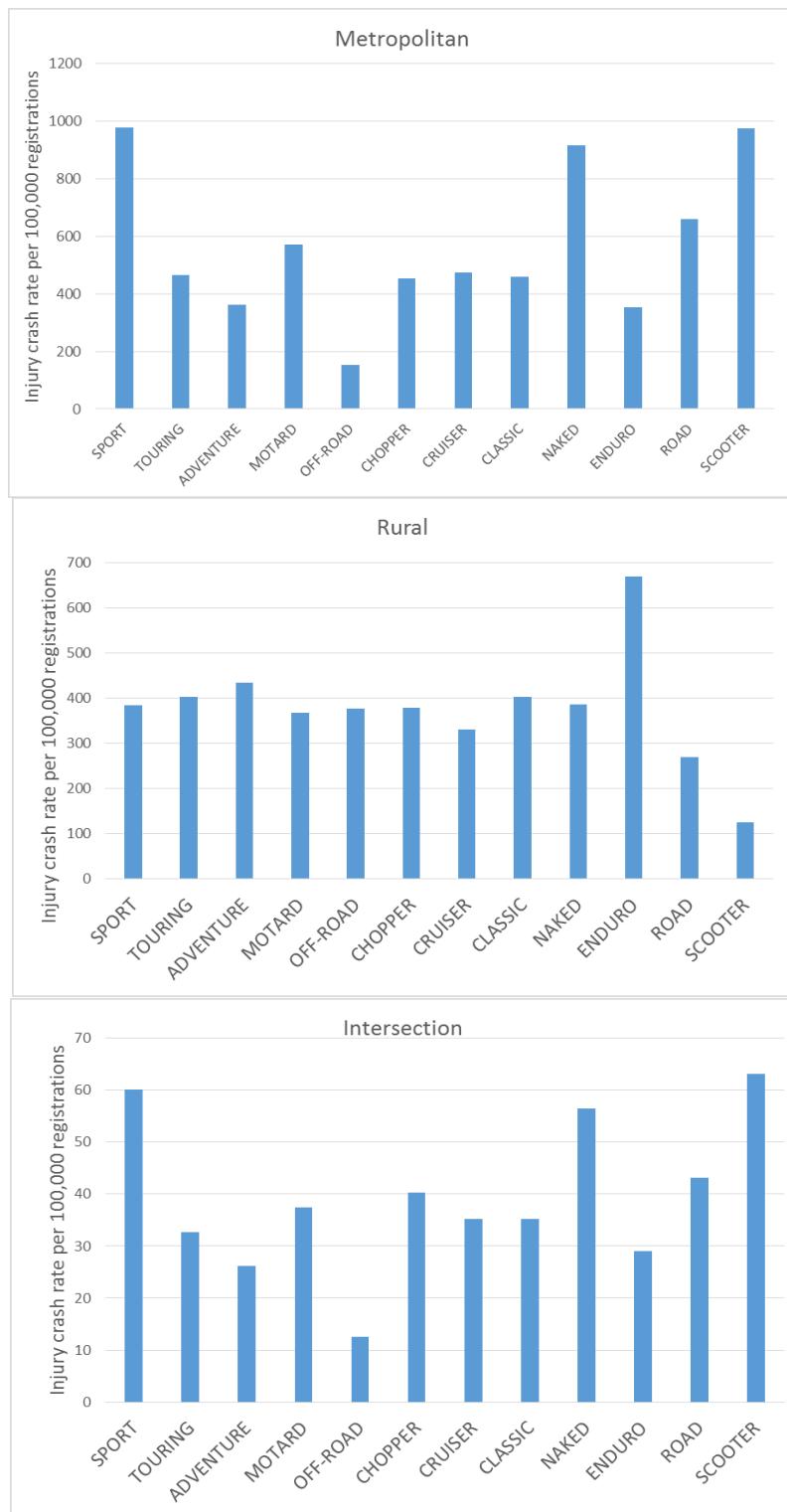


Figure 43 10-year average injury crash rates per 100,000 registrations by Redbook type and crash location⁴⁰

⁴⁰Denominators are registrations by Redbook type.

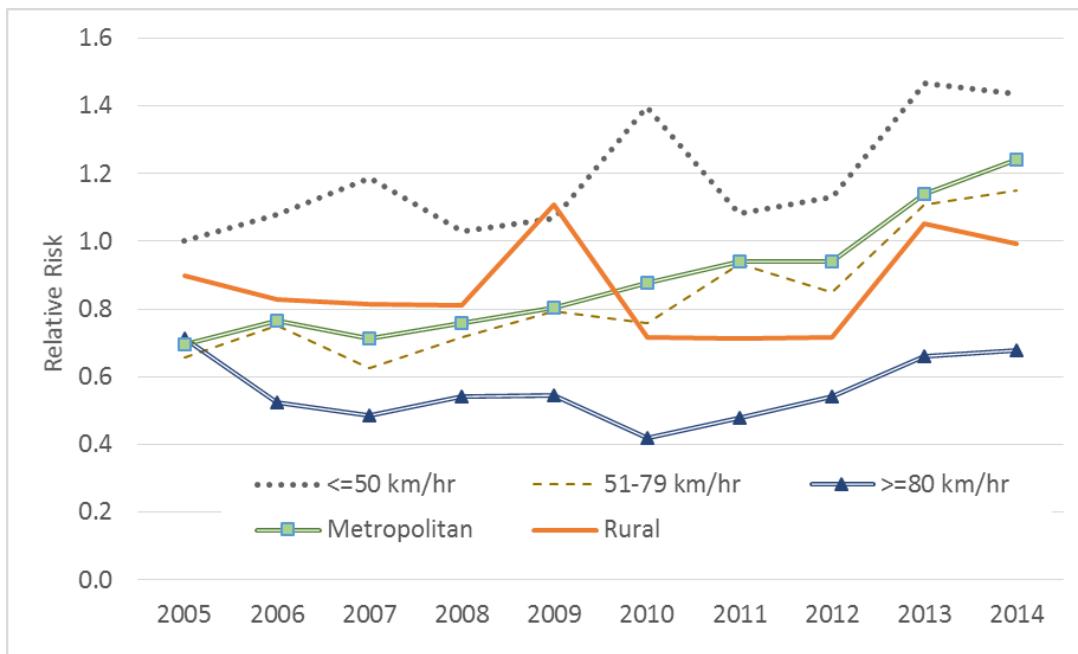


Figure 44 LAMS Ratio of location grouped injury crash rates per registration: Approved to Not Approved

When a ratio of crash rates by LAMS status, Approved to Not Approved was calculated (Figure 44):

- there was a trend of a decreasing crash injury outcome benefit associated with LAMS status over time;
- a lower crash rate was associated with *Approved* status in speed zones of 80 km/hr and over, at curves and in rural areas;
- until 2012, a lower crash rate was associated with *Approved* status in speed zones of 51-79 km/hr, at intersections and in metropolitan areas;
- a higher crash rate was mostly associated with *Approved* status in speed zones of 50 km/hr and under.⁴¹

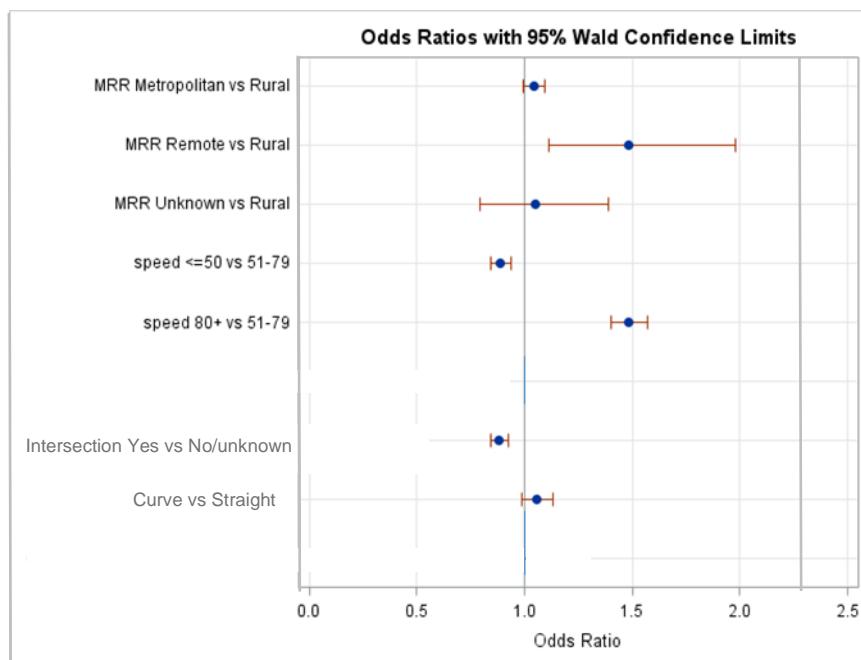


Figure 45 Odds ratio of a severe injury crash outcome by crash location

⁴¹This finding is likely to be confounded by rider experience or age.

Adjusted for rider, motorcycle and crash attributes, jurisdiction and registration year, the odds of a severe injury crash outcome significantly increased with speed zone:

- ≤50 km/hr zones had 11 (95%CI: 7-16, p<0.0001) lower odds than 60 and 70 (51-79) km/hr zones, and
- 80+ km/hr zones had 49 (95%CI: 40-57, p<0.0001) higher odds than 60 and 70 (51-79) km/hr zones.

The odds of a severe injury crash outcome were significantly:

- *higher* by 48% in remote regions than in rural (95%CI: 11-98, p=0.007), and
- 12% *lower* at intersections than not at intersections (95%CI: 7-16, p<0.0001).

It is important here to note that the intersection odds estimate is the contribution for the crash being at an intersection after the adjustment for particular crash types listed in Section 0.

4.13 Effect of crash conditions

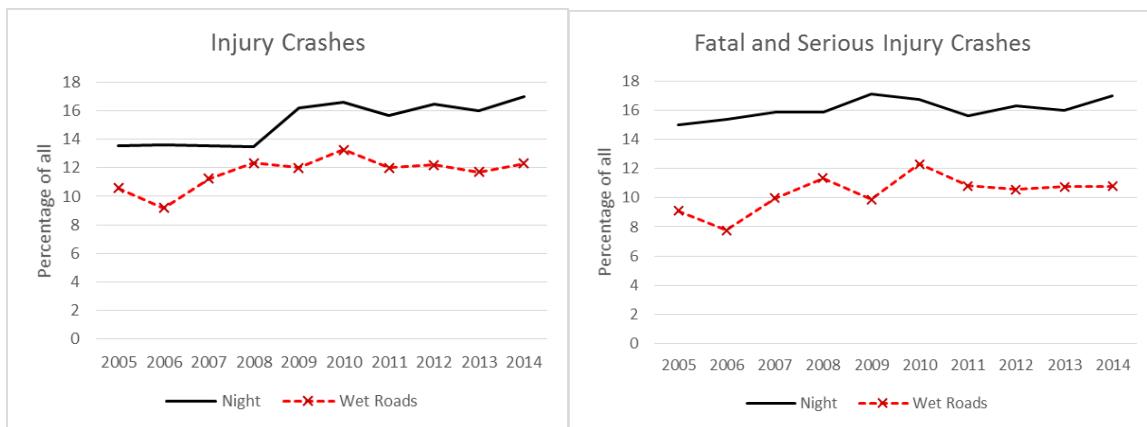


Figure 46 Proportion of injury crashes by crash conditions

Injury and fatal and serious injury crash proportions increased, to 2010, on roads recorded as wet; from then the crash proportions have been stable. The proportion of injury crashes at night rose slightly over the period (Figure 46).

- More than 80% of injury crashes were in daylight, however relative to day, night crashes were increasing.
- Almost 90% of injury crashes were on dry roads.

Crash rates at night and on wet roads have not increased over the period (Figure 47).

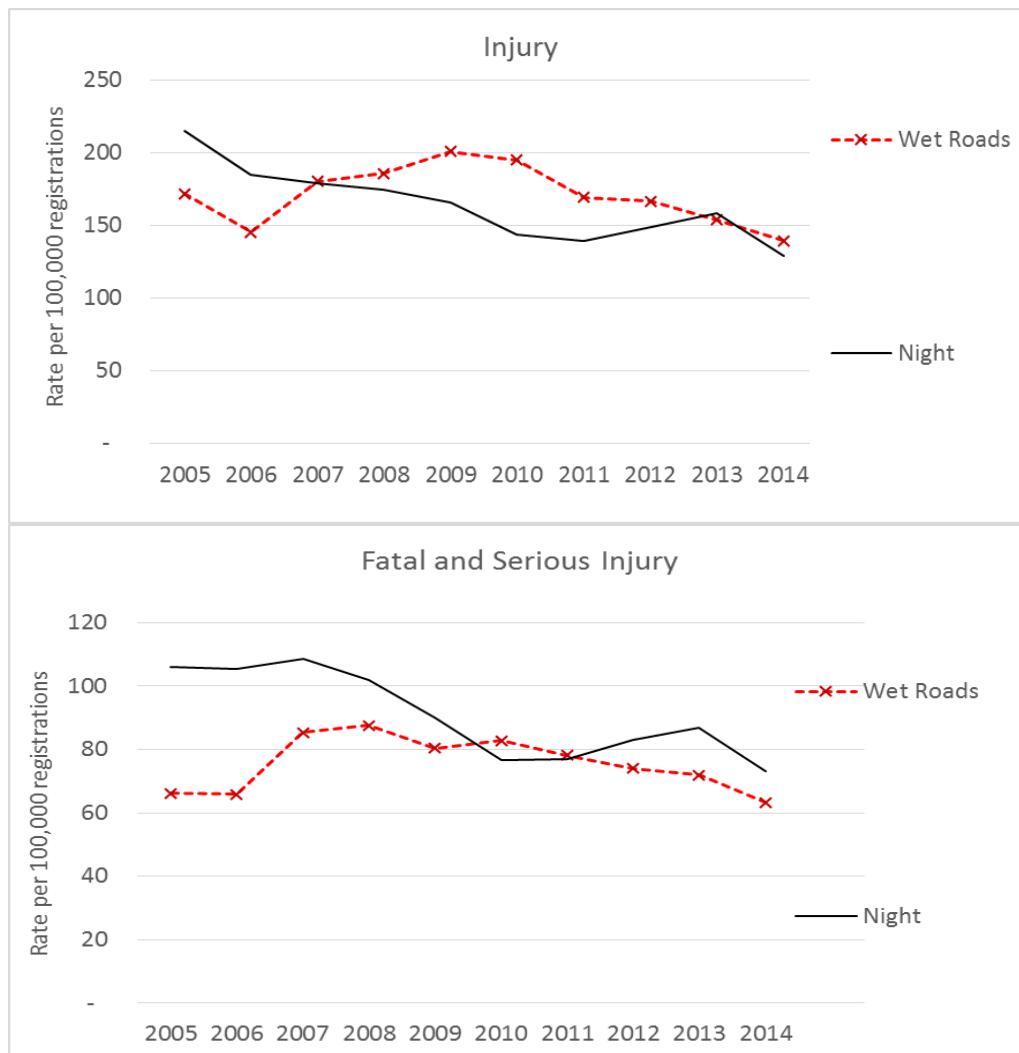


Figure 47 Crash rates per 100,000 registrations for crash conditions by crash year⁴²

During both the day and the night, injury crash rates were mostly lower for learner-approved motorcycles. On wet roads, higher injury crash rates were observed for learner-approved motorcycles (Figure 48). Again, there is a trend of a decreasing benefit associated with LAMS status over time, which is most likely also linked to rider age or experience.

⁴²Registrations have not been disaggregated into crash condition groups. ABS adjusted registration count is used as the exposure.

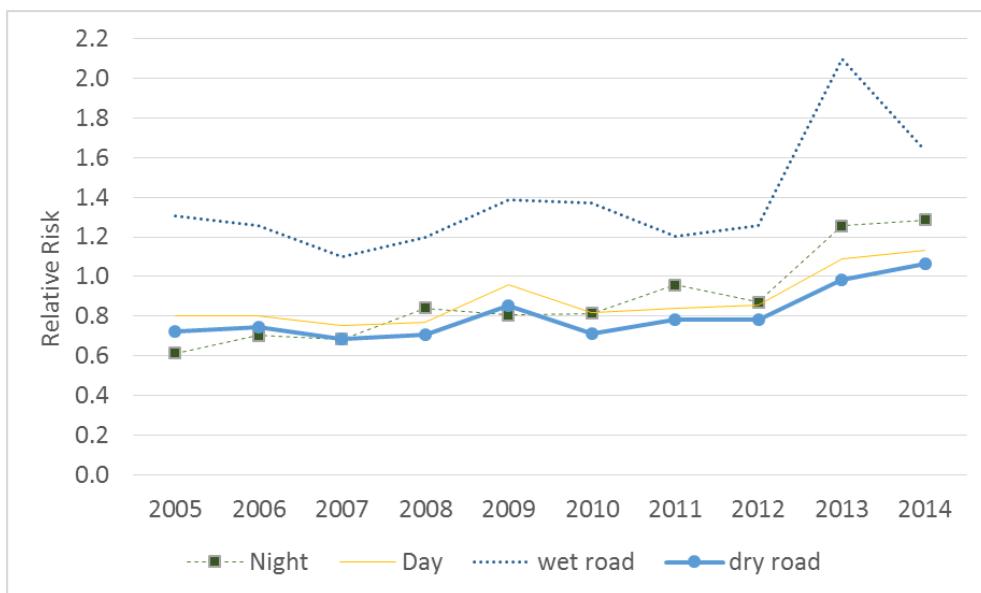


Figure 48 LAMS Ratio of condition grouped injury crashes rates per registration: Approved to Not Approved

Adjusted for rider, motorcycle and crash attributes, jurisdiction and registration year, the odds of a severe injury crash outcome were significantly higher (Figure 49):

- by 32% in dark conditions than in light (95%CI: 25-40, p<0.0001);
- by 12% in dusk/dawn conditions than in light (95%CI: 4-40, p=0.0048).

The odds of a severe injury crash outcome were significantly lower:

- by 19% in wet conditions than in fine weather (95%CI: 13-25, p<0.0001).

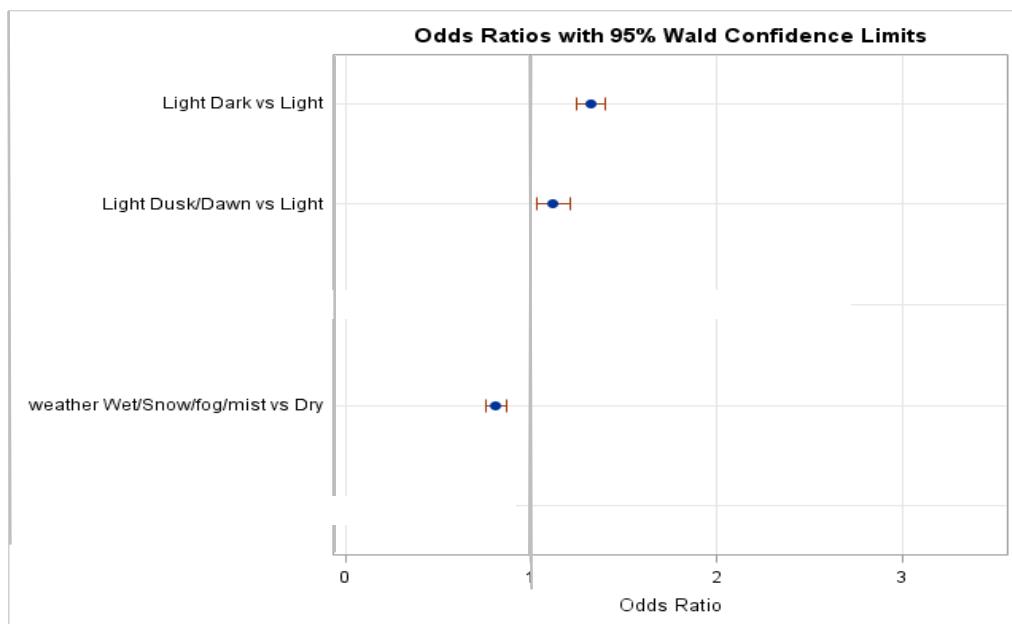


Figure 49 Odds ratio of a severe injury crash outcome by crash conditions

4.14 Effect of crash types

Figure 50 shows the percentage of each crash type of all jurisdiction injury crashes, in order to gather the relative importance of each crash type.

- Just under 60% of injury crashes involved another vehicle.
- 20% involved one vehicle turning in front of another.
- Only 4% were head on crashes.
- Except for single motor vehicle crashes, which slightly increased, the proportion of these crash types remained steady over the ten years.
- In some states speeding and BAC was recorded in the crash data. These as a cause of crashes have remained steady.

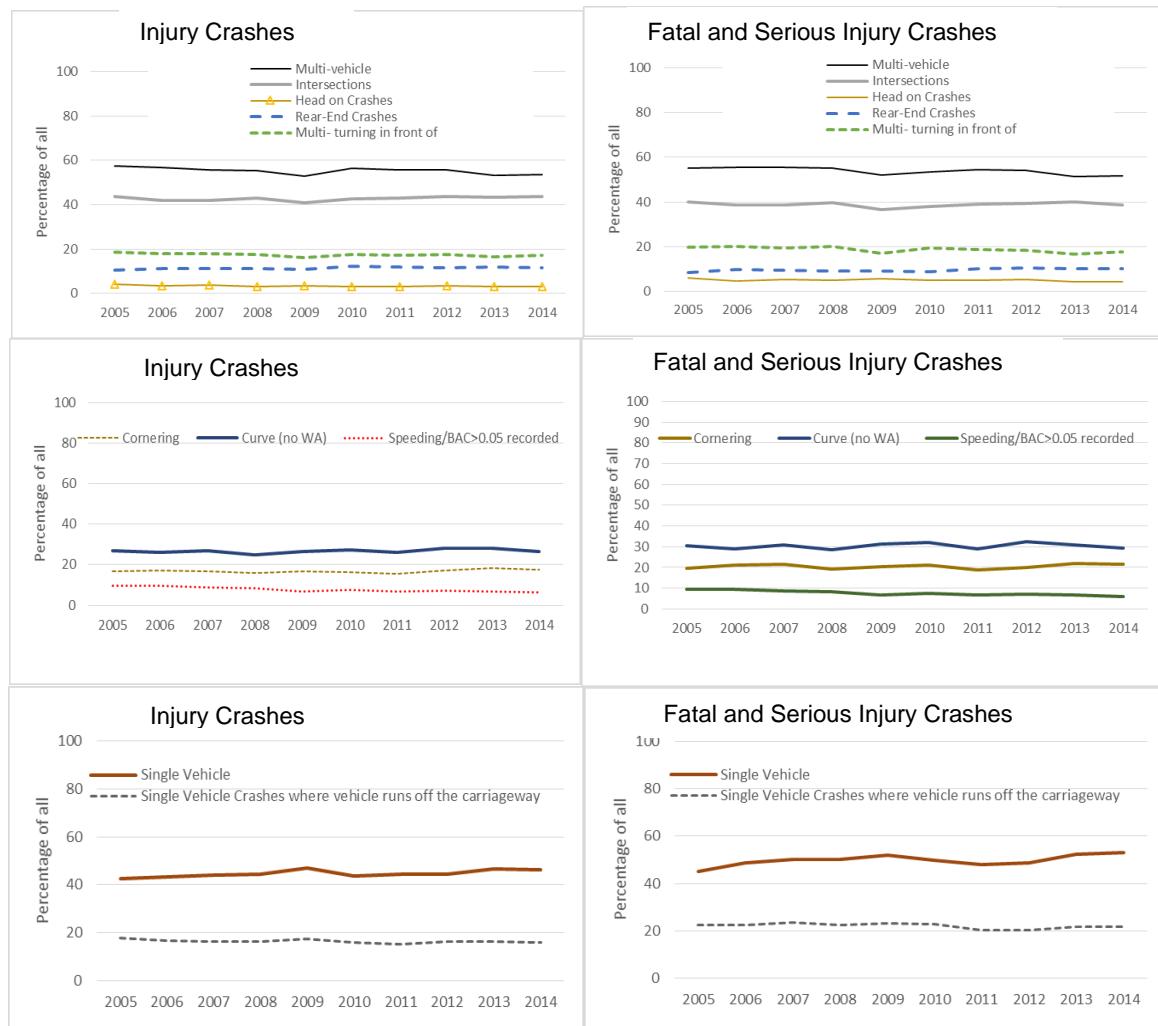


Figure 50 Proportion of injury crashes by crash types

All crash rates per registered motorcycle disaggregated by crash type decreased over the period (Figure 51). In ten years, motorcycle injury crash rates at intersections ranged from 700 per 100,000 registrations to 450 per 100,000 registrations, a decrease of about 36%. Similar risk increases were seen for other crash types. Registrations were not disaggregated by crash types.

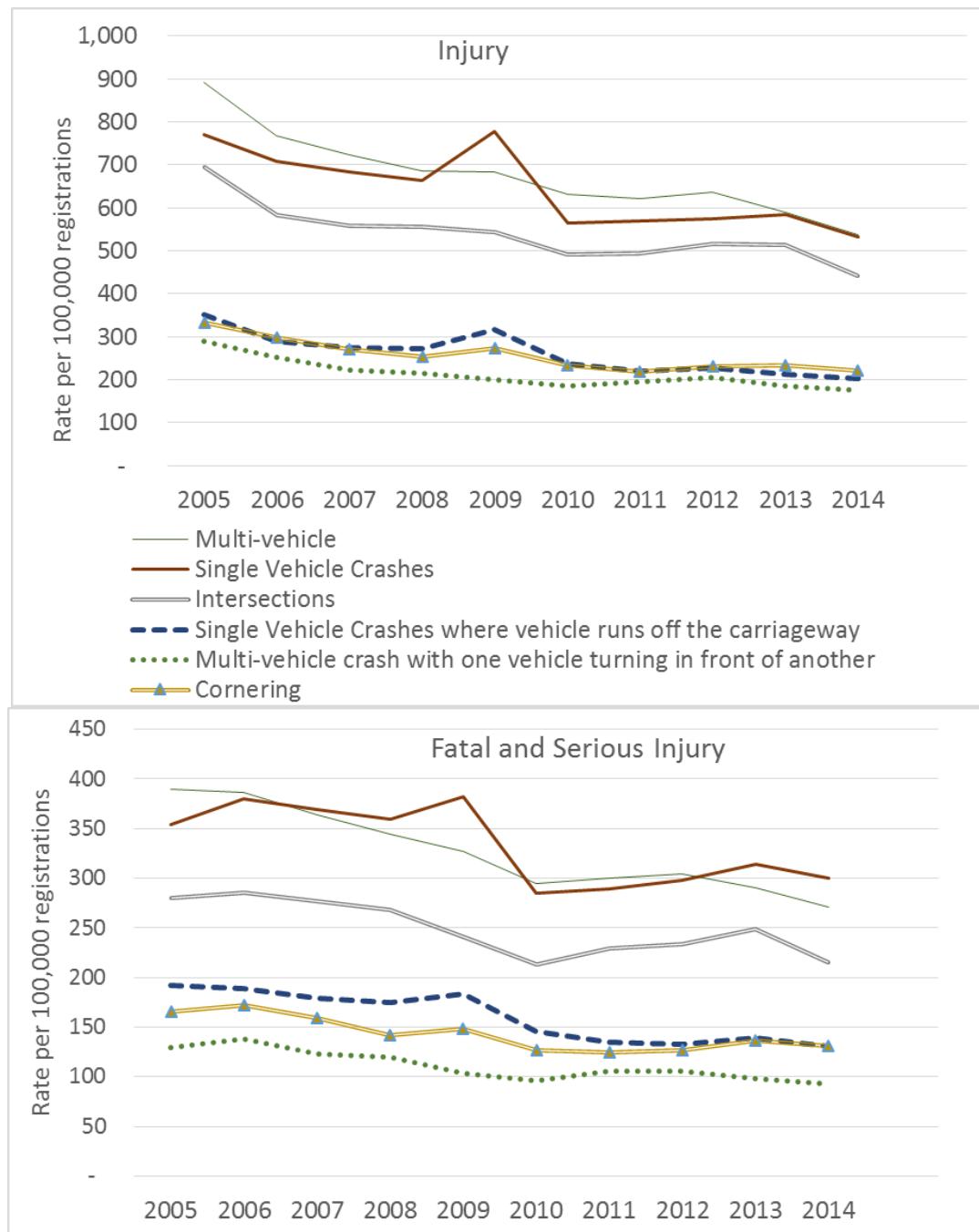


Figure 51 Crash rates per 100,000 registrations for crash types by crash year⁴³

For single motor vehicle crashes, another vehicle is not usually at fault, thus an examination of single vehicle crashes may proxy as a study on at fault vehicles. Averaged over the ten years, Enduro (off-road), Sport and Naked types displayed the highest single vehicle crash rates. Registrations were disaggregated by Redbook type (Figure 52).

⁴³Registrations are not disaggregated by crash types. ABS adjusted registration count is the exposure.

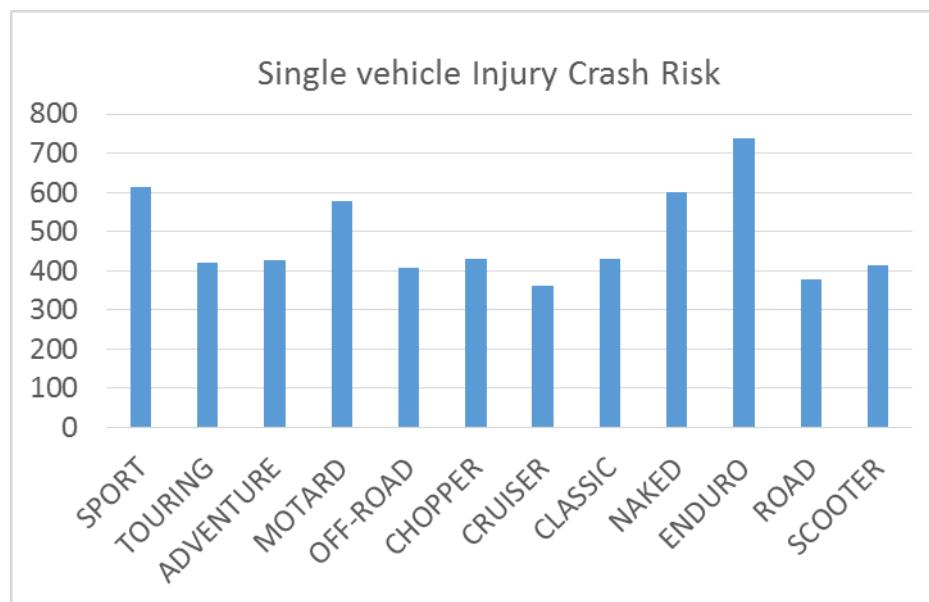


Figure 52 Average 10-year injury crash rates per 100,000 registrations by Redbook type and crash type⁴⁴

The association of LAMS status and decreased crash rates again decreased over time for the crash types being examined, however, all crash types displayed in Figure 53 had lower crash rates in the learner-approved group over almost the entire period. Note: Off-road excludes Enduro (a subcategory of off-road).

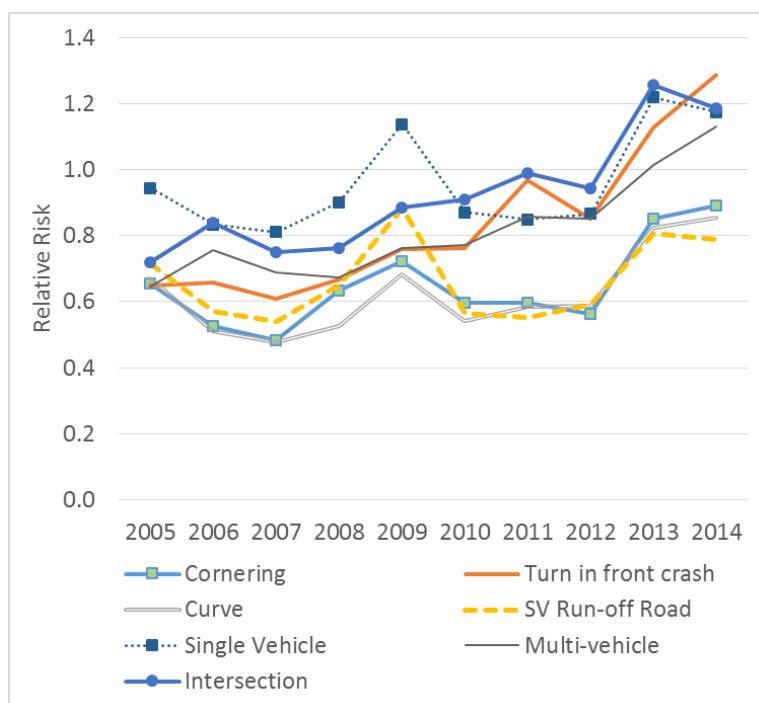


Figure 53 LAMS Ratio of crash type grouped injury crash rates per registration: Approved to Not Approved

Single run-off road crashes had the highest risk of a severe injury crash outcome amongst single vehicle crashes (Figure 54). After adjustment for jurisdiction, registration year and crash, rider and motorcycle attributes, single vehicle crashes

⁴⁴Denominators are registrations by Redbook type.

that remained on the carriage way compared with those that ran off the road had the odds of a severe injury crash outcome reduced by:

- 27% (95%CI:19 to 34, p<0.0001) if not involving loss of control (LOC);
- 34% (95%CI:29 to 39, p<0.0001) if involving loss of control.

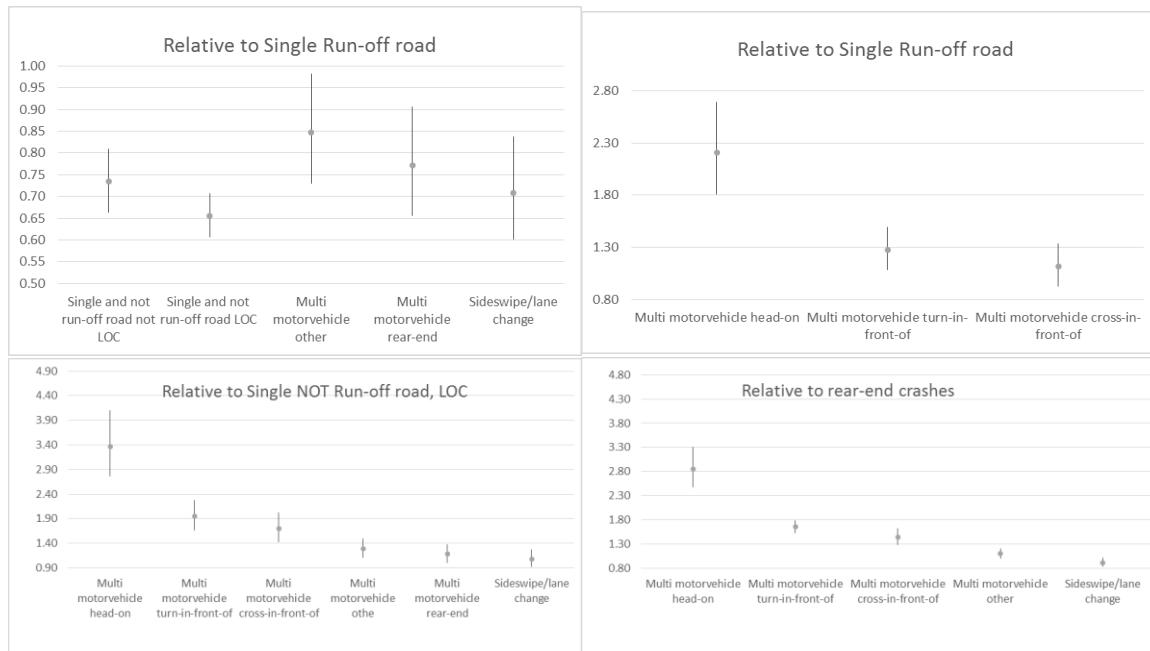


Figure 54 Odds ratio of a severe injury crash outcome by multi and single vehicle crash types

The ratio of the odds of a severe injury crash outcome for the two on carriageway single vehicle crash types (loss of control and not loss of control) were not found to be significantly different.

As the highest risk single motor vehicle type, single run-off road crashes were used as a reference crash type to compare other crash types in Figure 54.

Both 'other' and 'rear-end' multivehicle crashes were found to have lower odds of a more serious crash than single run-off road crashes, so multi-vehicle crash outcome comparisons were also made with the lowest risk single vehicle crash, the *on carriageway and loss of control*. Compared with these single vehicle crashes, all multi-vehicle crashes were at higher risk of more serious outcomes (Figure 54). Multi-vehicle crashes compared with *single vehicle on carriageway loss of control crashes* had the odds of severe injury crash outcome increased by:

- 3.36 times (95%CI:2.76 to 4.10, p<0.0001) if head-on;
- 1.95 times (95%CI:1.67 to 2.27, p<0.0001) if turn-in-front-of;
- 1.70 times (95%CI:1.43 to 2.03, p=0.005) if cross-in-front-of;
- 29% (95%CI:12 to 49, p=0.0003) if other;
- 18% (95%CI:18 to 38, p<0.0001) if rear-end;
- 8% (95%CI:-8 to 27, p<0.0001) if sideswipe/lane change.

To compare multi-vehicle crash types with one another, rear-end crashes were used as a reference (Figure 54). Multi-vehicle crashes compared with rear-end crashed had the odds of a severe injury crash outcome increased by:

- 2.86 times (95%CI:2.47 to 3.30, p<0.0001) if head-on;
- 65% (95%CI:53 to 79, p<0.0001) if turn-in-front-of;
- 44% (95%CI:28 to 62, p=0.005) if cross-in-front-of;
- 10% (95%CI:0 to 20, p=0.0003) if other.

Multi-vehicle crashes compared with rear-end crashed had the odds of a severe injury crash outcome decreased by

- 8% (95%CI:-1 to 16, p<0.0001) if sideswipe/lane change.

Figure 55 shows that the odds of a severe injury crash outcome were increased by:

- 16% (95%CI:9 to 23, $p=0<0.0001$) if an object or animal was hit;
- 44% (95%CI:18 to 75, $p=0.0002$) if a pedestrian was involved;
- 68% (95%CI:27 to 123, $p=0.0003$) if cornering and other motor vehicles involved;
- 6% (95%CI:-4 to 16, $p=0.0014$) if cornering and **no** other motor vehicles involved.

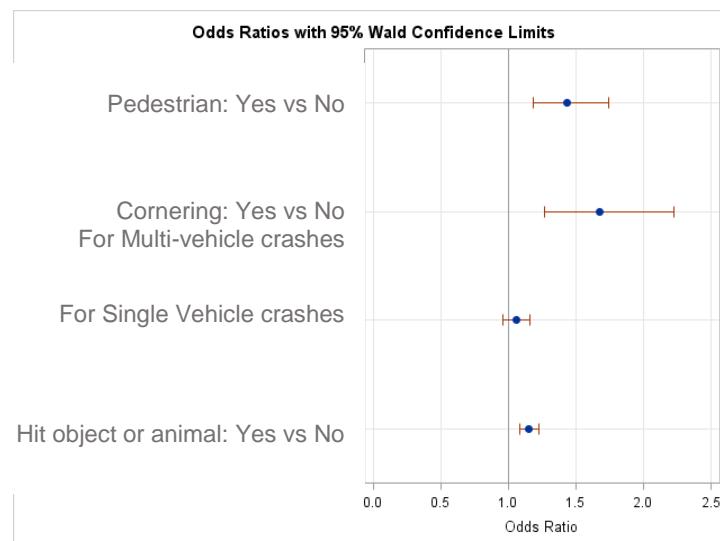


Figure 55 Odds ratio of a severe injury crash outcome by manoeuvre or object hit

For the *most* popular motorcycles, trends over time were examined for these crash types: metropolitan, rural, intersection and single vehicle (Figure 56). The following summarises observations for only these motorcycle and crash types:

- Sport, Scooter, Cruiser and Road types exhibit comparatively high metropolitan injury crash rates;
- Crash rates were highest at intersections for Scooters and Sport types;
- Only for Off-Road types were rural crash rates higher than metropolitan;
- Rural crash rates were highest for Sport and Touring types;
- Single vehicle crash rates were highest for Sport motorcycles;
- Most of the plotted trends, increased with time as for injury crashes generally, however, crash rates in these locations for Scooters remained stable.

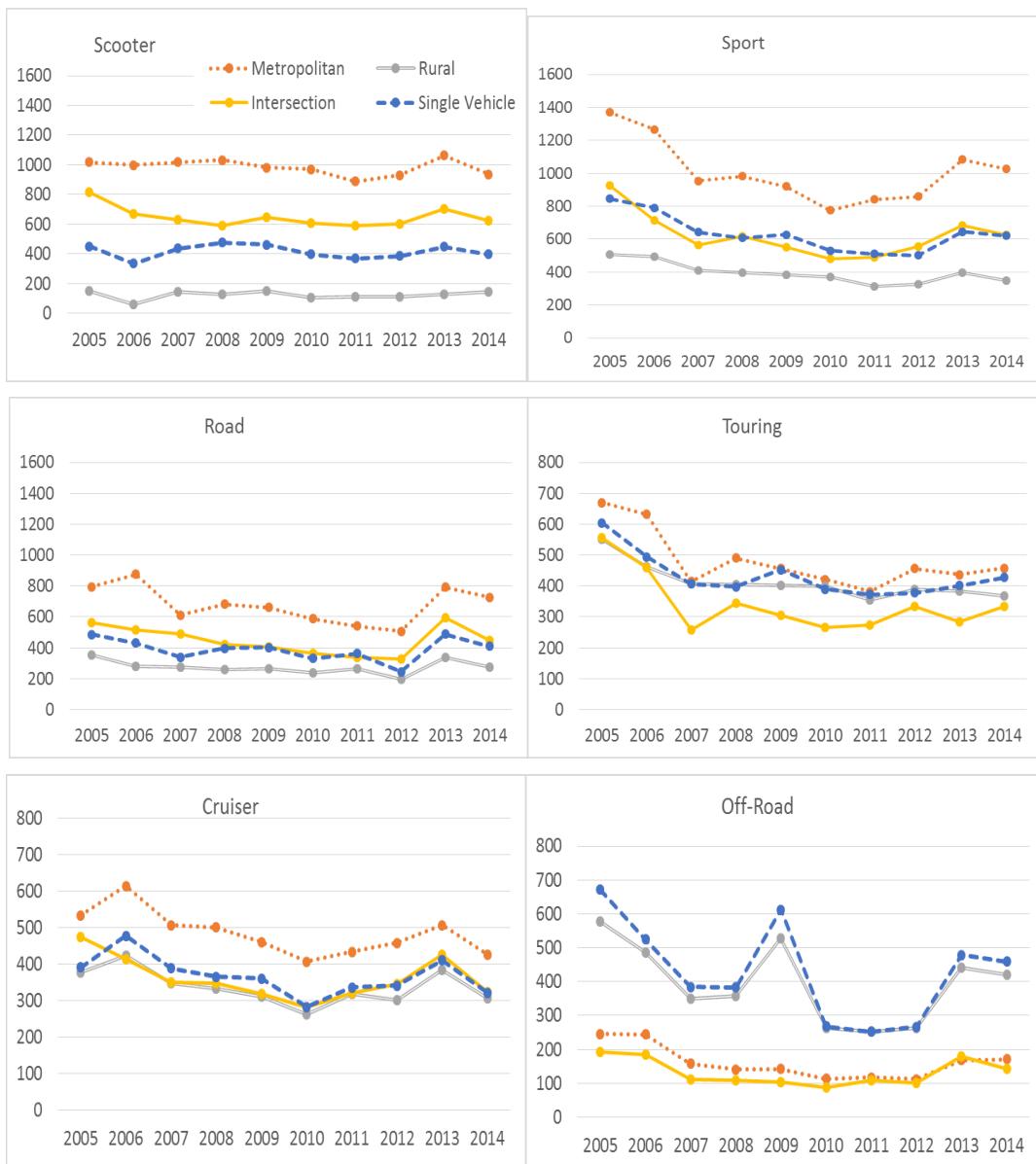


Figure 56 Specific type crash rates per 100,000 registrations (disaggregated) by Redbook type⁴⁵

⁴⁵The exposure is disaggregated by Redbook type and not ABS adjusted, so a dip in rates between 2007 and 2012 will result from the inflated NSW registrations.

PART 5 DISCUSSION

5.1 Limitations of using registrations as the measure of exposure

This study used registration counts to estimate exposure for crash risk estimates. Although registrations may generally be used in this manner for passenger vehicles, the patterns of usage for motorcycles are very different from that of passenger vehicles, with kilometres travelled for each motorcycle a much more accurate exposure measure. While many motorcyclists use their motorcycle as their primary transport in a similar fashion to passenger vehicle drivers, a significant proportion of registered motorcycles are not used as a primary means of transport. When these mostly-garaged motorcycles are used, it is more likely for recreation than for transportation. The type of motorcycle will often be an indicator of its pattern of usage. Large motorcycles, Touring, Enduro and other Off-road motorcycles will more likely be used for recreation and smaller motorcycles, scooters and mopeds are more likely to be used for commuting. In addition, Off-road motorcycles are probably going to spend most of their on-road time (i.e. on sealed public roads) in a trailer. Thus, a limitation of this study is that exposure is likely to be over-estimated (and hence risks under-estimated) for recreational and Off-road motorcycle types.

Police reported crash data was used to estimate injury crash numbers and rates. There is also a group of motorcyclist injury crashes that are unreported. Unreported injuries to motorcyclists was identified in a Victorian auditor-general's report (2011), which suggested that police reported crashes captured less than half of hospital emergency presentations and admissions, particularly those involving off-road motorcycling. While this highlights a need to improve our understanding of both off-road motorcycle crashes and on-road crashes involving lower levels of injury, the findings presented here remain highly relevant to serious injury motorcycle crashes on public roads. In addition, while hospital-based data may provide more accurate estimates of all motorcycle-related injuries, there is no current mechanism for linking of vehicle, licence and crash data that was necessary for the analysis conducted for this report.

5.2 Overall trends in crashes and crash/crash severity risk

Motorcyclists had a worse outcome in injury crashes than passenger vehicle drivers, and this became worse over the ten years investigated here. Adjusted for motorcycle attributes, jurisdiction and registration year, the injury crash risk approximates 1.0% and the fatal or serious injury crash risk approximates 0.5%. Just under half of all injury crashes result in fatal and serious injuries. The relative rate of fatal and serious injury crashes to minor injury crashes also increased by around 80% over the ten years. In contrast, only about one quarter of the passenger vehicles from Police reported injury crashes are recorded as involved in fatal and serious injury crashes.

Motorcyclists are vulnerable to impacts with other vehicles, the ground and road infrastructure (ETSC, 2008) and lower speeds on impact decrease the severities of injuries (ACEM 2004) and give the rider more time to react to a situation. Thus, countermeasures to address the high proportion of injury crashes with severe outcomes generally include the use of effective protective clothing, protective road infrastructure, appropriate speed limits, speed limit enforcement and protective technologies.

Promotion of the use of effective protective clothing is recommended. This may involve better education or providing national standards on protective clothing after a successful evaluation of the use of protective clothing to improve outcomes generally. A star rating system for motorcycle protective clothing is currently being developed. It is noted that with the exception of helmets, the benefits of wearing motorcycle protective are likely to apply most to reducing lower severity injuries (ACEM), and that other strategies are required to significantly reduce fatal and serious injury crashes.

Motorcycle helmet use is well known to reduce the severity of injuries from a crash and this study has quantified injury crashes where a helmet was *not* worn as associated with 72% higher odds of a severe injury crash outcome, relative to wearing a helmet. Thus, it is recommended that enforcement for helmet wearing continues even though only 3% of crashed riders could be identified as not wearing a helmet and this decreased from 5% to 2% over the ten years.

Frangible roadside furniture, furniture without sharp edges, and barrier support guarding (Oxley, 2011) may also offer impact protection to the rider.

Whilst inappropriate speed limits and recommended speed limits in high crash risk areas generally could be identified and addressed, this study has identified some particular areas on which to focus. This study has found that that 20% of motorcycle injury crashes occur whilst cornering, and that intersections account for 40% of motorcycle injury crashes. In addition, the odds of a more severe injury crash outcome were estimated at 68% ($p=0.0003$) higher if the crashed motorcycle was cornering in a multi-motor vehicle crash (relative to not cornering). With the scope for improvement at intersections and corners established, targeted speed lowering strategies could be employed. Lower speed limits at intersection approaches may be one such strategy since Walton and Buchanan (2011) have shown that motorcycles travel faster than the prevailing traffic on intersection approaches and it may be implied that a faster approaches have led to impaired motorcycle conspicuity and more serious rider injuries on impact. About twice the proportion of passing motorcycles were exceeding the speed limit when compared to other vehicle types for selected sites in Victoria (Allen et al, 2017). Increased targeted camera enforcement of speed, where the cameras can identify motorcycles from the rear, may be another possible strategy to lower speeds at the approaches to corners and intersections.

It is generally recommended that Police continue with, or increase frequency of, speed enforcement for both motorcyclists and other road users (given the high proportion of multi-vehicle crashes and their more serious injury outcomes). If enforcement fails to improve compliance to speed limits, it is recommended that Intelligent Speed adaption be used as penalty for recidivist speeders (Oxley 2011, NSW Centre for Road Safety 2010) and for general use to help riders maintain speeds within limits.

Lastly, airbags may be associated with an overall benefit in reducing injury severity (Ulleberg 2003). This is currently a relatively new development area for motorcycles requiring further development and research.

5.3 Multi-vehicle crashes

Over 50% of motorcycle injury crashes were multi-vehicle crashes. A prevalent location for multi-vehicle crashes is the intersection, which is often located in a low speed limit zone. Although intersections are the most prevalent motorcycle injury crash location, after covariate adjustment (which included crash type), motorcyclist injury outcomes were estimated to be better in injury crashes that took place in lower speed zones and at intersections. (Intersection and low speed crashes were also likely to be located within metropolitan regions.) After covariate adjustment, the odds of a severe injury crash outcome were lower by 12% ($p<0.0001$) if the crash was at an intersection (relative to not at an intersection), where about 40% of injury and serious and fatal injury crashes occur. Similarly, the odds of a more severe injury crash outcome were lower by 11% ($p<0.0001$) if the speed zone was 50 km/hr and under (relative to 51-79).

Despite the lower risk of a severe injury crash outcome associated with intersection and low speed environments, multi-vehicle motorcycle injury crashes were found to have more serious outcomes (relative to single vehicle crashes) generally. Relative to single vehicle, (and adjusted with covariates including intersection location) on carriageway, loss of control, injury crashes, the odds of a severe injury crash outcome were higher for multivehicle crashes: 3.36 times ($p<0.0001$) if head-on, 1.95 times ($p<0.0001$) if turn-in-front-of, 1.70 times ($p=0.005$) if cross-in-front-of, 29% ($p=0.0003$) if *other* multi-vehicle, 18% ($p<0.0001$) if rear-end and 8% ($p<0.0001$) if sideswipe/lane change. In addition to having more severe injury crash outcomes generally, the scope for improvement in multi-vehicle motorcycle injury crash outcomes is established with its high 50% injury crash incidence. The seemingly contradictory severity findings for intersection and multivehicle injury crashes show that the crash type, rather than the location, is the greater contributor to a more severe outcome. Thus, countermeasures designed for intersections need to specifically address the crash types with the poorest injury outcomes for riders.

As motorcycles are often not seen, measures which improve rider conspicuity, such as those discussed by Oxley (2011) are recommended to counter multi-vehicle crash risk and crash severity. In this report, the effects of poor rider conspicuity were observed as crashes in poor ambient light conditions; the odds of a severe injury crash outcome were 32% ($p<0.0001$) higher if in dark conditions (relative to light) and higher by 12% ($p=0.0048$) if in dawn/dusk conditions (relative to light). However, the effects of rider conspicuity was not obvious in poor weather conditions. The odds of a severe injury crash outcome were 19% ($p<0.0001$) lower if crash was in wet/foggy or snowy weather (relative to dry), indicating, that the ambient light in wet weather is less of an issue, and this odds ratio may be indicative of the weather causing motorists to slow down and be more careful. This report indicated that the problem of poor conspicuity may be increasing: the proportion of injury crashes on wet roads and at night increased over the period.

The use of daytime running lights (DRL) on motorcycles has mixed views on its effectiveness at reducing injury crashes through increased conspicuity (Oxley 2011) in low ambient light conditions. A recent MUARC study of the association of DRL in passenger vehicles and injury crashes found no benefit associated with passenger vehicle crashes involving unprotected road users. However, the use of modulating headlights has been shown to improve conspicuity in a different study (Shaheed et al. 2012). This is an area worthy of further research.

High visibility clothing has been found to improve outcomes in low ambient light, glare and poor weather as well as multi-vehicle crashes generally. Wells et al (2004) showed that crash risk was higher for riders wearing darker helmets, and riders wearing any reflective or fluorescent clothing had a 37% lower risk of crash related injury than other riders. Scope for improvement was established in 2016 (Allen et al.) in their findings that over half of passing riders were wearing dark colours with no fluorescent or reflective surfaces. However preliminary data from the case-control arm of the same study found no reduction in crash risk for riders wearing bright or reflective clothing. Therefore, while the use of clothing for increased visibility is recommended, further research is required. Some jurisdictions now make this a requirement for learners, so a future evaluation of this policy using crash data is possible.

There are motorcycle technologies that target multi-vehicle crashes as well as collisions with persons, animals or objects. These may need further evaluation by simulation or by real-world crash analyses as they penetrate the fleet. Such technologies are Motorcycle Autonomous Emergency Braking (MAEB) systems, which are still being developed and evaluated (Savino 2013) and Collision warning systems (CWS). Such technologies can monitor following distance, warn of impending collisions, warn of departures from lanes and in the case of MAEB autonomously apply braking, however more work needs to be done with respect to their effectiveness in motorcycles and their acceptance by riders (Oxley 2011). Since multi-vehicle crashes are often the result of a failure to notice even after looking, additional warning systems are likely to be of some benefit, even if they are fitted to passenger vehicles rather than motorcycles. In fact, the most common primary contributor in multi-vehicle crashes (54%) has been found to be a traffic scan error in the other road user (Allen et al 2017). Further crash evaluations of the benefits to motorcyclists when CWS or autonomous emergency braking systems are fitted to passenger vehicles may be worthwhile.

The strategies targeting rider speed discussed in the previous section are also relevant in multi-vehicle crash mitigation. In Victoria, inappropriate rider speed was found to be associated with forms of rider error for multi-vehicle crashes (Allen et al, 2017).

5.4 Single-vehicle crashes

Injury crashes in rural areas and on open roads are of concern. There were greater proportions of motorcycle injury crashes (but decreasingly so over 10 years) than population proportions would predict in remote and rural areas. Thirty-five (35%) of injury crashes (and 40% of serious injury crashes) were in rural or remote regions and just under 30% (and just over 30% for fatal and serious injury crashes) occurred in speed zones of 80 or more. Injury crashes were more likely to have severe outcomes (and increasingly so) in more remote regions and in higher speed zones; the odds of a severe injury crash outcome were 48% higher ($p=0.007$) if the crash region was remote (relative to rural) and the odds of a more severe injury crash outcome increased with increasing speed zone. The odds of a more severe injury crash outcome were lower by 11% ($p<0.0001$) if the speed zone was 50 km/hr and under (relative to 51-79). The odds of a more severe injury crash outcome were 49% ($p<0.0001$) higher if speed zone was 80 km/hr and over (relative to 51-79).

Rural and open road locations are frequently where single vehicle run-off road crashes occur. Although single motorcycle crashes were found to have less severe outcomes than multi-vehicle motorcycle crashes, the odds of a severe single vehicle injury crash outcome were higher for motorcycles leaving the carriageway relative to staying on the carriageway. The odds of a severe single vehicle injury crash outcome were about 30% lower if the vehicle remained on the carriageway.

Road infrastructure may be improved to address single and multi-vehicle motorcycle injury crash rates and crash severities in high speed zones, on open roads and in rural locations as well as at intersections (40% of injury crashes) and for turn-in-front-of (20% of injury crashes) injury crashes. The road environment, (mostly in the form of design and maintenance issues), has been identified as a secondary contributor to Victorian motorcycle crashes in 78% of cases and has been identified as a primary contributor in a higher proportion of single vehicle than multi-vehicle crashes (Allen et al. 2017). Allen identified common road design issues as poor intersection design, poorly signed roads, reduced road widths and fixed obstructions. Maintenance issues were identified commonly as loose material on the road and a poor road surface condition.

Infrastructure has been evaluated by MUARC for VicRoads and the TAC generally, but it may be necessary to design an evaluation specific to motorcycles to find the most cost-effective infrastructure improvements. In the recent Safer Road Infrastructure Project (SRIP) evaluation (Budd & Newstead 2016), significant rider injury reductions⁴⁶ were associated with the following treatments: shoulder sealing (29%) and shoulder sealing and hazard removal (58%). In the recent SRIP evaluation, significant fatal and serious rider injury reductions were associated with the following treatments: intersections in metropolitan areas (61%), rural road segment (52%), shoulder sealing (41%), traffic signal treatments (75%), new traffic signal installations (91%), right turn modification (63%), installation of fully controlled right turn and extension/installation of right turn lane (80%). Road infrastructure suggested countermeasures are: suitable barrier instalments to reduce run-off road injuries in targeted locations and bends (Oxley, 2011), skid resistant surfaces and improved road surfaces generally which help motorcyclists maintain control given the inherent instability of a two-wheeled vehicle, dedicated turning lanes to reduce turn-in-front-of crashes, signs and shrubs that do not obscure motorcycles and improve conspicuity and fully controlled signals for turns which reduce turn-in-front-of crashes.

There are motorcycle technology systems that mitigate high-speed run-off road and cornering crashes. Most of these systems will need further evaluation of efficacy by simulation or by real-world crash analyses as they penetrate the fleet. An anti-lock braking system (ABS) is one such system that has already been proven effective with real-world crash data (Rizzi et al, 2009 and 2015). The inherent instability of motorcycles is exacerbated when braking: locking the wheel by braking increases the risk of losing control, particularly when applied in emergencies, so that the motorcycle frequently falls before actually colliding with the obstacle (Oxley, 2011, Ouellet, 2006). Technology systems, such as ABS, which address ineffective braking are effective countermeasures for single vehicle crashes because ineffective braking has been identified as a large contributor to these crash types (Hawthorn et al. 1997). Also more effective braking from ABS is likely to give the rider more control and time to implement corrections to a misjudged situation; Allen et al. (2017) identified rider misjudgement or control as the most common primary contributing factor (51%) in single vehicle motorcycle crashes in Victoria. Preliminary findings from the same study showed reduced crash risk for those riding a motorcycle fitted with ABS.

Obviously, braking technologies need to work with speed lowering strategies (of Section 5.2) because excessive speed for conditions is also an important contributor to both multi- and single vehicle crashes. From January 2016, ABS has been mandated in Europe for all new motorcycles with greater than 125cc engine capacity. Strategies to increase uptake of ABS into the Australian fleet are recommended.

In addition to ABS, another potentially useful technology in single vehicle crash mitigation is an Advanced Rider Assistance System (ARAS). This system provides warnings to the rider if their approach speed to a hazard is

⁴⁶Estimated reductions are in brackets.

inappropriate. Such hazards currently include curves and intersections. These systems are limited by rider acceptance and price (SAFERIDER 2010, Huth & Gelau 2013).

5.5 Overall trends in motorcycle attributes: registrations and risk

Injury and fatal and serious injury crash risks were found to be associated with increases in PWR; a 150 kW/t motorcycle was estimated to be associated with an 8.7% higher odds of an injury crash and a 12.2% higher odds of a serious injury crash than a 50 kW/t motorcycle (after adjustment for type and engine capacity). Although influential in crash risk, PWR was found to have only a small contribution to the injury crash severity; odds ratio estimated increases were found to be 0.5% for each 100 kW/t increase in PWR.

The effect of PWR on crash risk is a concern when the proportion of higher PWR motorcycles within the registered fleet is considered. Motorcycles with a power-to-weight ratio exceeding 150 kW/t make up in excess of thirty percent of registrations, and annual registrations of motorcycles with a power-to-weight ratio of 350 kW/t or more almost doubled over the period.

Engine size was estimated to be a larger contributor to the injury crash severity than was PWR; a 200 cc motorcycle was estimated to have 2.6% higher odds of a severe injury crash outcome than a 100 cc motorcycle. The effect of engine capacity on crash severity was not found to be significantly different by motorcycle type. However, Off-road and Road motorcycle types were found to be associated with an increased risk of an injury crash with increasing engine capacity, and Off-road, Road and Motard motorcycles were found to be associated with an increased risk of a fatal and serious injury crash with increasing engine capacity. A 200 cc Off-road motorcycle was estimated to have ten times the odds of an injury crash than a 100 cc Off-road motorcycle. This increase was 1.5 times higher when comparing the odds ratio for 200 cc and 100 cc Road types. A 200 cc Off-road or Motard motorcycle was estimated to have a 12% higher odds of a fatal or serious injury crash than a 100 cc Off-road or Motard motorcycle. The odds ratio was only 3% higher when comparing 200 cc and 100 cc Road types, suggesting a relatively greater increase in risk for off-road motorcycles of larger engine capacity. These increases in risk are of concern considering that motorcycles with engine capacities of 750 cc or more make up more than one third of registrations, and motorcycles with at least 250 cc engine capacity make up more than two thirds of registrations. In addition, registrations for larger engine capacity motorcycles have increased over the ten years compared to those of 250cc capacities or less.

It is recommended that the trends in changes to the distribution of vehicle types and attributes in the registered motorcycle fleet continue to be monitored. Possible intervention could involve incentives such as discounted registrations for vehicles with a lower PWR. As increased injury crash risk was only associated with engine capacity increases for certain motorcycle types, and only small increases in crash severity risk were associated large engine capacity increases, incentives based on engine capacity are not recommended.

5.6 Safest motorcycle types

Touring and Off-Road types were significantly less likely to be involved in an injury or serious injury crash relative to all other types. It is possible however, that off-road injury crashes are under-reported using police reported crashes (due to location and remoteness factors), so should be treated with caution. Riders of Off-road types were at increasing injury crash risk with increasing engine capacity and had the highest risk of a fatality or serious injury in an injury crash. As a result, the evidence from this study finds ranks Touring motorcycles as the safest type. Riders of Touring motorcycles also were rated as having the lowest risk of serious or fatal injury in an injury crash.

The profile for Touring motorcycles is as follows:

- Ranked 7th in popularity, comprising less than 10% of 2005-2014 registrations;
- Odds of an injury crash were 25% (95%CI: 20-30, P<0.0001) lower than all other types;
- Odds of a fatal or serious injury crash were 32% (95%CI: 25-39, P<0.0001) lower than all other types;
- Odds of a severe injury crash outcome were 16% (95%CI: 9-22, P=0.007) lower than all other types;
- Odds of an injury crash reduced by 6.1% (3.9-8.3, p<0.0001) with each 1cc increase in engine capacity;
- Odds of a fatal or serious injury crash reduced by 0.03% (0.00-0.07, p=0.0001) with each 1cc increase in engine capacity;
- Odds of a severe injury crash outcome were not affected by engine capacity;
- Injury crash prevalence indicates that they were highly represented amongst:
 - older vehicles
 - in rural areas
 - with 60 year and over riders
- One of the lowest proportions of learner approved motorcycles in registered motorcycles (14%).

5.7 Least Safe Motorcycle Types

The three most popular (amongst registrations) types were likely to also be the three least safe of motorcycle types.

Off-road motorcycles were estimated to have the highest risk of a severe injury crash outcome, yet the lowest risk of an injury crash. This makes sense, since an off-road usage would indicate that they are more likely to be ridden for “thrills” and they are less likely to be on roads (where Police reported crash data arises and) where both the crash counts and the true exposure occur. The over-estimation of their true exposure means that their true (road) crash risk is likely under-estimated. As the most prevalent type amongst registrations, their true (road) crash risk may make them the most unsafe motorcycle type.

Off-road motorcycles also present a greater injury crash risk with increasing engine capacity and have a high proportion of registrations that are learner approved. Injury crash prevalence indicated that they were highly represented amongst riders aged under 25 years and unlicensed riders.

Next to the Off-road motorcycles are Sport motorcycles which were the second most prevalent type, yet still ranked second for risk of injury crash and second for risk of fatal or serious injury crash. Sport motorcycles were amongst the types with the lowest proportion of learner-approved registrations. Their injury crash risk decreased with an increasing engine capacity. The injury crash prevalence of Sport motorcycles indicated that they were highly represented amongst older vehicles, riders under 25 years, probationary riders, unlicensed riders, single vehicle crashes, metropolitan crashes and intersection crashes.

Cruisers rated second for odds of a severe injury crash outcome and third in registrations. It is possible that the exposure for Cruisers is also over-estimated by registrations, as they are a type popular for recreational usage, so will often only come out of the garage on the weekend. Cruiser motorcycles were amongst types with the lowest proportion of learner-approved registrations. The injury crash risk decreased with increasing engine capacity for Cruiser motorcycles. Injury crash prevalence indicated that they were highly represented amongst older vehicles and female riders.

5.8 LAMS status

More than half of the RVCS matched 2005-2014 motorcycle fleet was found to be learner approved; this included all of the 250cc and under, half of the 251-749 cc motorcycles, all of the 50 kW/t PWR motorcycles and 70% of the 51-150 kW/t power-to-weight ratio motorcycles. Only three of the most popular motorcycle types had 50% or more 2005-2014 registrations that were learner approved: Road, Off-road and Scooter.

Generally learner approved motorcycles were associated with a lower injury crash rate⁴⁷ than *Not Approved* motorcycles, however associations with higher injury crash rates were found for the 51-150 kW/t band, speed zones of 50 km/hr and under, wet roads and some Redbook types (Sport, Cruiser, Touring and Naked). These Redbook types represent around half of registrations, and the PWR band represents one quarter of registrations. Speed zones of 50 and under host about a quarter of injury crashes. Thus, these *exceptions* make up a significant subset of injury-crashed motorcycles.

The average absolute difference between crash risks for *Approved* and *Not Approved* motorcycles decreased with time for both injury and fatal and serious injury crash rates, so that by 2014, there was no difference between raw crash rates for *Approved* and *Not Approved* groups. Further investigation by rider age, found that the relative increases in the *Approved* injury crash rates mainly occurred for the group of riders aged under 25 years. For under twenty-fives, the injury crash rate ratio ranged from 1.71 in 2005 to 3.16 in 2014. For the 25 years and older groups, the crash rate for learner-approved motorcycles remained fairly stable over the entire period, with the ratio of the injury crash rate of *Approved* to *Not Approved* motorcycles ranging from 0.64 in 2005 to 0.89 in 2014. It appeared that the ‘overall rider age’ potential crash benefit from LAMS status was over-powered by the additional crash risk imposed by the rider’s age. Because all probationary and learner riders are required to ride learner (LAMS) approved vehicles, the injury crash risk associated with LAMS status was confounded with rider experience.

In addition, LAMS status, through model testing (likelihood ratio & AIC), was found not to perform as well as PWR and engine capacity (without or with a Redbook type covariate) in predicting injury crash risk. Given the relationship of LAMS status with rider age, it would have been of great interest to have registration data with ‘owner age’ or ‘years of licensing for the owner’ as a variable, so that the injury risk analysis could have been performed with an age or experience adjustment, however, these data were not available. With registration data as currently provided, the evidence to support the current definitions of LAMS status as an indicator of crash risk shows that LAMS status does not provide information as full as other possible predictors do and that its influence is confounded by other variables not present in the registration data.

LAMS status is defined by limits to both engine capacity and power-to-weight ratio (PWR), so the ability of LAMS status to predict injury crash risk is dependent on the ability of these two variables to predict injury crash risk themselves. For PWR, this relationship was found to be so. About 66% to 69% of registrations had a PWR value of 150 kW/t or lower; the

⁴⁷14% lower odds of and injury crash and 30% lower odds of a fatal or serious injury crash, p<0.0001, when corrected for jurisdiction and registration year.

odds of an injury crash over this range of PWR values were estimated to differ by a maximum of 13%⁴⁸ for motorcycles of the same jurisdiction, registration year, engine capacity and type. The association of engine capacity and injury crash risk was found to be more complicated. In its categorical form, with only year, jurisdiction and year of manufacture as covariates, crash risk was estimated to increase with increasing engine size, however when modelled with an adjustment for PWR and Redbook type the injury crash risk decreased with increasing engine capacity. To further complicate matters, when an interaction of engine size with Redbook type was included in the regression model, the relationship varied with motorcycle type; for Off-road (except Enduro), Road and Motard types injury crash risk increased with engine capacity and for Sport, Touring, Cruiser, Naked and Enduro types the injury crash risk decreased.

Through model testing, Redbook type was found to contribute significantly to the crash risk prediction model. Thus, the type of motorcycle appears to be a missing factor needed in the definition of LAMS, and it appears that engine capacities may need to be set at different limits for different motorcycle types.

5.9 Riders

The proportion of female riders involved in injury crashes increased over the ten year period, averaging 10% overall. Female riders trended toward younger vehicles and males toward older vehicles. It is recommended that the growing proportion of female riders be considered when planning and implementing rider safety strategies so that implemented strategies are inclusive of both genders and consider gender specific trends.

One-fifth of crashed riders were not on their full licence. Unlicensed riders involved in injury crashes increased in proportion and had poorer injury outcomes. The odds of a more severe injury crash outcome were greater by 25% ($p=0.02$) if the rider was unlicensed (relative to Full licence). Amongst motorcycle age groups, the greatest proportions of unlicensed riders were found for injury-crashed motorcycles older than 16 years. It is recommended that Police continue with licence checks to remove unlicensed riders from our roads and improve compliance.

Just under a quarter of injury crashed riders were aged under 25 and about 15% of injury crashed riders were using probationary or learner licences. Learner riders were likely to be riding older motorcycles and likely to have poorer injury outcomes. The odds of a severe injury crash outcome were greater by 12% ($p=0.035$) if the crash was for a learner rider (relative to Full licence). Raw injury crash rates for probationary riders increased over the period.

Injury crashes increased for older riders. The proportion of riders aged 60 years and older involved in injury crashes doubled (from 3-7%) over the ten years, as did the raw crash rates for this age group. Older riders had poorer injury outcomes. The odds of a severe injury crash outcome increased with rider age and were found higher by 39% ($p<0.0001$) if the rider was aged 60 years and over (relative to 25-59). The proportion of injury crashed older riders across motorcycle age groups increased with motorcycle age.

Licence assessment or re-training is recommended for older riders, to pre-empt expected increases in net serious injury and fatalities for this group due to the ageing population. A reduced crash risk associated with more years of on-road riding experience has been established in Victoria (Allen et al. 2017), however, older riders may actually be returning to riding after an absence or trying for the first time, so some extra training could improve their skill and bring them up to date with current road conditions.

The Victorian older road user study over 2006-2015, found that older riders experienced growth in licensing of almost 300% and within the licensed, the learner permits doubled over the period 2006 to 2015. The Victorian older road user study over 2006-2015, also found that older motorcyclists were more likely to be on open roads which at higher speeds makes them more vulnerable. It also found them more likely to have injuries when stopped or manoeuvring. Thus, it may be that some targeted training in both low speed and high-speed skills may improve their crash risk and injury outcomes.

⁴⁸Redbook type was included in model.

PART 6 CONCLUSIONS

This evaluation of factors associated with motorcycle crash risks and injury outcomes covers ten years of data and uses well established modelling techniques to identify and quantify the magnitude of associated risks. It is limited by the exposure group measure in registration data, which is likely to under-estimate risks for motorcycles primarily used for recreation rather than for transport. However, the estimates for the odds of a severe injury crash outcome are unaffected by exposure and thus provides a telling picture of the highest risk factors in the event of a reported injury crash.

A unique feature of the study was the ability to study factors affecting crash risk and injury outcomes for motorcyclists related to motorcycle type and other attributes including engine capacity and power to weight ratio. Crash rates and injury outcomes varied significantly by motorcycle type. Furthermore, those motorcycle types with the highest crash risk and highest risk of serious injury outcomes, namely sports motorcycles, are becoming more prevalent in the fleet, which is adversely affecting motorcycle safety. Further adverse effects on motorcycle safety are stemming from the trend to increasing power to weight ratio of newer motorcycles which has shown a significant association with more severe injury outcomes in a crash. Analysis results also suggest that the effectiveness of the LAMS criteria could also be improved by considering motorcycle type in the restriction criteria.

A number of countermeasures have been suggested or recommended to redress the identified high risk factors and the trends in registration and crash data. Some areas for further study have been identified, including:

- Strategies to increase the conspicuity of motorcycles, including a crash evaluation on learner mandated high visibility clothing, and further research on potential benefits of modulating headlights;
- A motorcycle specific road infrastructure evaluation;
- An evaluation on the effects of autonomous emergency or assisted braking in passenger vehicles on motorcycle crashes and an evaluation of rider experience within the crash risk and crash severity models presented here;
- Further research to understand unreported injury crashes, particularly those involving off-road recreational motorcycling in remote or regional areas;
- New strategies to gain more accurate estimates of exposure for motorcycling on public roads.

In addition, some recommendations were made including:

- Reduction of speed limits where appropriate in high speeds zones and rural/remote areas;
- Promotion of the wearing of high quality protective and reflective clothing;
- Promotion of the uptake of ABS fitted motorcycles and new vehicle crash prevention technologies for other vehicles;
- Promotion of programs to update rider skills for older riders learning or returning to riding after long periods of absence.

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PART 8 APPENDICES

8.1 Logistic Regression Modelling details

Several injury crash prediction models were proposed which used various forms of motorcycle attributes found within registration data. These were presented in *Table 6*. Models (i) and (ii) used a categorical engine capacity, year of manufacture and all available annual registrations. Models (iii) to (iv) used only registration data matched with RVCS data and did not use year of manufacture as a motorcycle attribute. Instead, these three models used different combinations of LAMS status, Redbook type and (continuous variable forms of) engine size and power to weight ratio. In addition, the interaction of engine capacity and Redbook type were examined within the context of model (iv).

Using the Akaike Information Criterion (AIC) and Schwartz Criterion (SC) and likelihood ratio goodness of fit statistics, the models of *Table 6* were compared. *Table 11* presents the ‘goodness of fit’ statistics for the models presented in *Table 6*. It presents the goodness of fit statistics with Redbook type modelled as a multi-value categorical variable for model (iv).

The likelihood ratio tests of models ii and iii of *Table 6* were significant, indicating that, engine capacity and power to weight ratio combined, were a better predictor of injury crashes than LAMS status.

LAMS status was not included in model (iv) of *Table 6* because it was not as good a predictor of an injury crash as engine capacity and PWR, and it was found to have collinearity with engine capacity to the degree that including LAMS status in model (iv) made engine capacity have no significant contribution to injury crash prediction.

Overall, the models with both engine capacity and power-to-weight ratio fared best as predictors of an injury crash; however, the inclusion of Redbook type improved the injury crash prediction model.

TABLE 11 GOODNESS OF FIT STATISTICS FOR TABLE 6 LOGISTIC REGRESSION MODELS

model	Akaike Information Criterion	Schwartz Criterion	Log likelihood ratio and degrees of freedom
Injury Crash Models			
I	304,907	305,403	2,462.49 38
ii	238,002	238,164	2,009.13 12
iii	239,112	239,261	897.06 11
iv	236,503	236,790	3,469.53 22
Fatal and Serious Models			
I	15,7653	15,8149	157,575 38
ii	122,030	122,192	1098.62 12
iii	122,527	122,676	599.96 11
iv	121,466	121,753	1,654.93 22

Log-likelihood testing and the comparison of goodness-of-fit statistics were also used to compare the crash logistic regression models of *Table 7*, even if only approximately nested. These models were used to estimate the odds of a more severe injury crash outcome (given that the motorcycle was already involved in an injury motorcycle crash). These models did not use registration data, and included crash data of all jurisdictions. In addition to these six models, the interaction of engine capacity and Redbook type was examined within the context of model (v).

Comparisons of models (ii) and (iii) of *Table 7* showed that the covariates of engine capacity and power-to-weight (ii) were significantly better predictors of a more serious outcome than was either of LAMS status (iii) or Redbook type (iv) alone. In combination with Redbook type, engine capacity and power-to-weight (v) were also significantly better predictors of a more serious outcome than was LAMS status (vi). Moreover, the model (v) addition of Redbook type to model (ii) produced a significant improvement.

8.2 Correlations

Correlated variables were modelled.

Power with weight

Power and tare weight were somewhat correlated ($p=0.6$). These two variables were combined into a single variable measured in kW per tonne, using the LAMS defined relationship:

Engine power (kW) $\times 1000$

$$\frac{\text{Tare weight (ie mass of motorcycle in kg)} + 90\text{kg (80kg rider weight + 10kg for fuel)}}{(1)}$$

Correlation with engine size

Power divided by weight, power and weight were all significantly correlated (<0.0001) with engine size. Tare weight had the strongest correlation ($\rho=0.91$ $p<0.0001$) with engine size. The correlation of engine size and power was only 0.7 and the correlation of engine size and the power-to-weight ratio was even lower at 0.5. Correlation plots showed strong visible trends for engine size both with tare weight and with power, however the *power-to-weight ratio* relationship with engine capacity appeared to be influenced by some outliers, and was otherwise more "blobby" (uncorrelated & random) than linear in appearance.

Thus the motorcycle attribute *power-to-weight ratio*, which was least correlated with engine capacity, was used in the logistic regression analyses with engine capacity. It was also the form used in the definition of learner-approved motorcycles.

Correlation with LAMS status

By definition, both engine capacity and power-to-weight ratios are negatively correlated to LAMS status. Electric learner approved motorcycles have a power output not in excess of 25kW. Non-electric learner approved motorcycles have a maximum engine capacity of 660 cubic centimetres⁴⁹ and unless manufactured prior to December 1960, have a maximum power-to-weight ratio of 150 kilowatts per tonne. The correlation of LAMS status and engine capacity was estimated with correlation coefficient of -0.83 ($p <.0001$) and the correlation of LAMS status and power-to-weight ratio was estimated with a correlation coefficient of -0.72 ($p<0.0001$).

8.3 Linearity of continuous variables within the logistic relationship

Two continuous variables were modelled: power-to-weight ratio in kilowatts per tonne as defined in (1) and engine capacity in cubic centimetres. These were first modelled on registration data in Model (ii) of *Table 6* and then in the much smaller data set of models (ii) and (v) of *Table 11*. Within both datasets, Box-Tidwell testing of the relationship were carried out. The power-to-weight ratio was found not to need transformation; however, a square root transformation was suggested for engine capacity within the injury crash model. Within the fatal and severe injury crash model, no relationship with engine size was found, so a zero power transformation was suggested by the Box-Tidwell test. For the injury crash models, partial logit plots of both untransformed and square root transformed versions showed a few influential outliers and a large 'blob' (random and uncorrelated) of coordinates. Further Box-Tidwell testing of the regression relationships with the transformed variables produced no other transformation suggestions.

Analyses of injury crash risk were carried out using a square root transformation of engine capacity. No continuous variable transformations were used in the analyses of fatal and serious injury crash risk nor in the crash severity analyses.

8.4 Effect of Registration Year on Injury Crash Risk

The trend for the odds of an injury crash (per registered vehicle) was modelled with:

- i. full data (≥ 1990 YOM and non-missing engine size), and the covariates: YOM and engine size categories;
- ii. reduced (RVCS matched) data and the covariates: continuous engine cubic capacity and power to weight;
- iii. reduced data and the covariate LAMS status;
- iv. reduced data and the covariates: continuous engine cubic capacity and power to weight, and Redbook type.

Each odds ratio estimate for registration year had a virtually identical magnitude (to 2 decimal places) regardless of the model used. The odds ratios relative to 2005 are depicted in Figure 57 for model (ii); they are scattered around the value of 1.00.

⁴⁹There are some non-approved model exceptions with engine capacities under 260 cc (see cited websites for details).

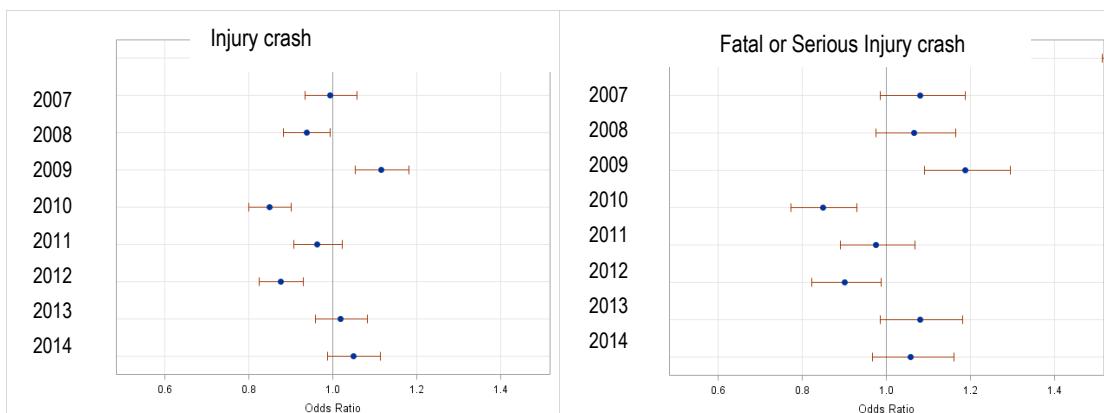


Figure 57 Odds of an injury crash and the odds of a fatal or serious injury crash, for each registration year, relative to the base year of 2005 (with 95% confidence intervals)

The predicted probabilities from the modelling of the odds of a severe outcome in a **metropolitan** injury crash are presented for the *reduced* model (v) for each jurisdiction and at reference levels for all other covariates in Figure 58. The results were almost identical for rural regions.

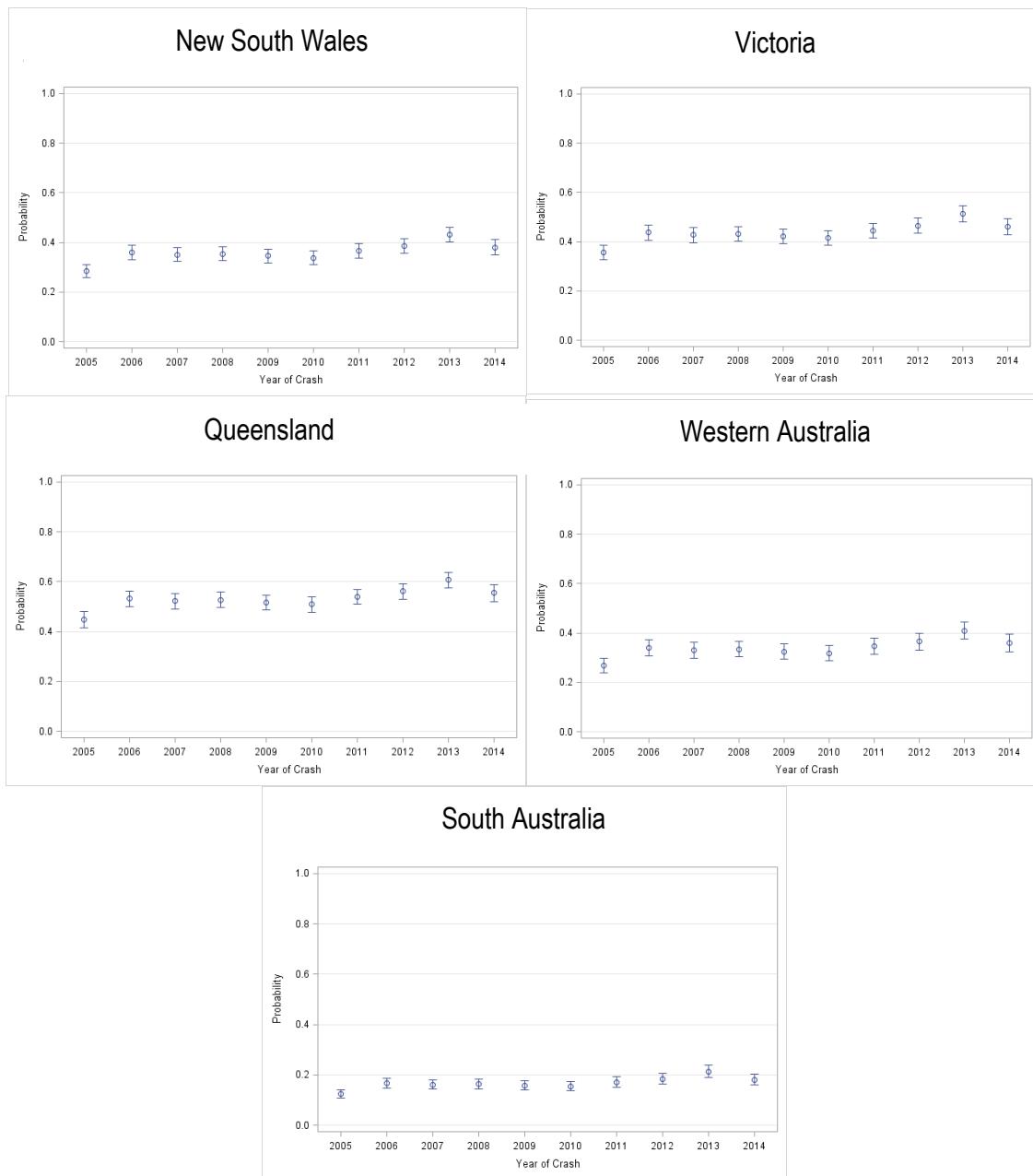


Figure 58 Predicted probability of a severe injury crash outcome for each registration year and jurisdiction, for metropolitan regions, at average capacity and power-to-weight ratios and reference values of other covariates ($\alpha=0.05$, model v)

8.5 Alternative modelling of Redbook types

Figure 59, Figure 60 and Figure 61 demonstrate the injury crash risks associated with different Redbook types where each type is compared against all others. Each chart clearly presents the hierarchy of types from highest to lowest risk.

When compared simultaneously with all other types, the only types that did **not** exhibit higher odds of an injury crash than all other types were Touring and Off-road. Specifically, after adjusting for PWR, engine capacity, registration year and jurisdiction, Touring motorcycles had a 25% (95%CI: 20-30, $P<0.0001$) lower odds of an injury crash than every other type and Off-Road had a 38% (95%CI: 29-47, $P<0.0001$) lower odds. At the other end of the spectrum, Enduro (off-road), Sport and Naked exhibited the highest risks relative to all other types, with, respectively, an estimated 90%, 50% and 38% higher odds of an injury crash.

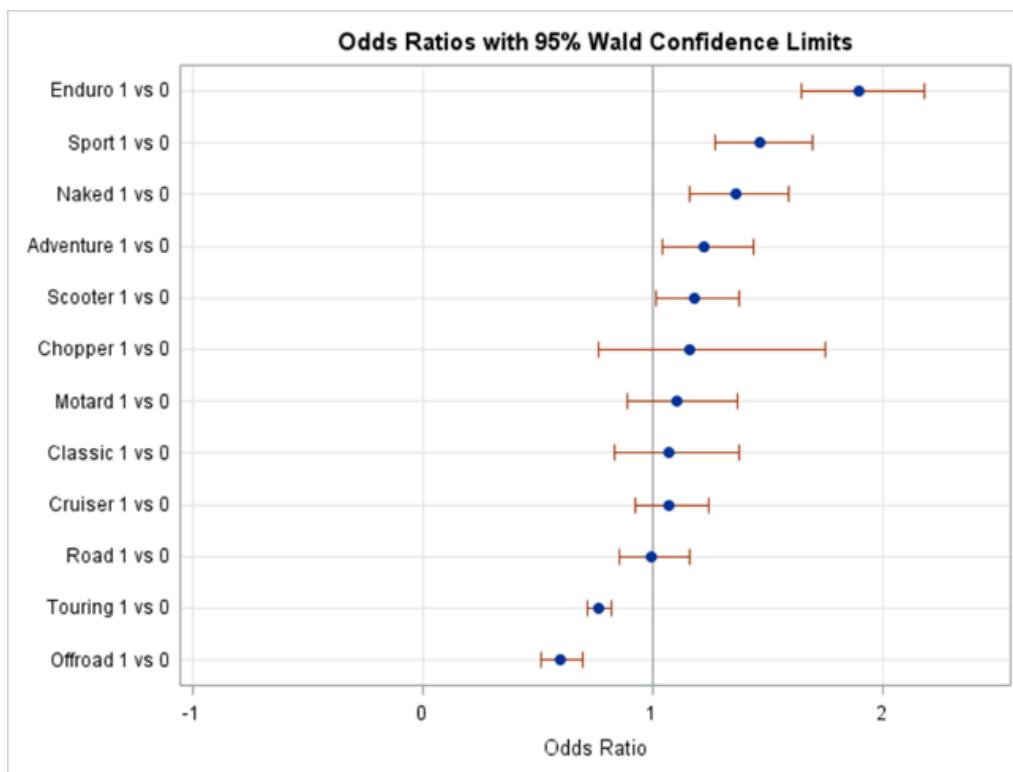


Figure 59 Odds of an injury crash by Redbook type (2005 to 2014) referenced against all other types

When compared simultaneously with all other types, the only types with a well evidenced and lower odds of a fatal and serious injury crash than all other types were Touring, Off-road and Road. Specifically, after adjusting for PWR, engine capacity, registration year and jurisdiction, Touring motorcycles had a 32% (95%CI: 25-39, P<0.0001) lower odds of a fatal or serious injury crash than every other type and Off-Road (except Enduro) had a 42% (95%CI: 27-53, P<0.0001) lower odds. At the other end of the spectrum, Enduro, Sport and Naked exhibited the highest estimated risks relative to all other types, with respectively an estimated 103%, 31% and 26% higher odds of a fatal or serious injury crash.

When compared simultaneously with all other types, Cruiser and Off-road exhibited a higher odds of a severe injury crash outcome than all other types, although the odds ratio was only significant for Off-road. Specifically, after adjusting for PWR, engine capacity, registration year, jurisdiction and crash covariates, Off-road had a 13% (95%CI: 4-22, P<0.0001) higher odds of severe injury crash outcome than every other type. At the other end of the spectrum, Road, Scooter and Touring exhibited the lowest risks relative to all other types, with respectively 8%, 10% and 16% lower odds of a severe injury crash outcome.

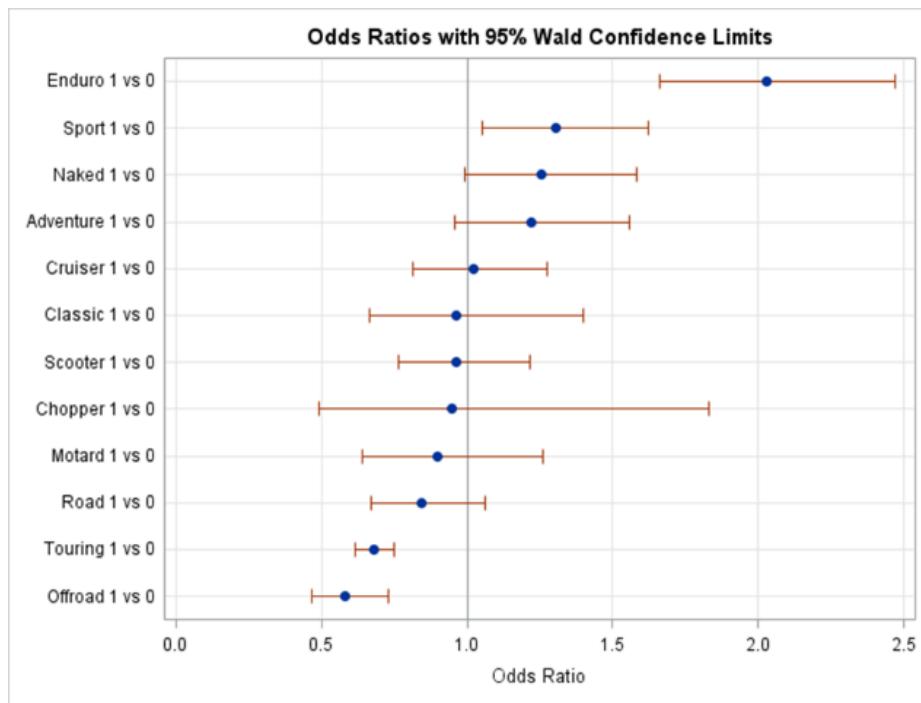


Figure 60 Odds of a fatal or serious injury crash by Redbook type (2005 to 2014) using referencing against all other types

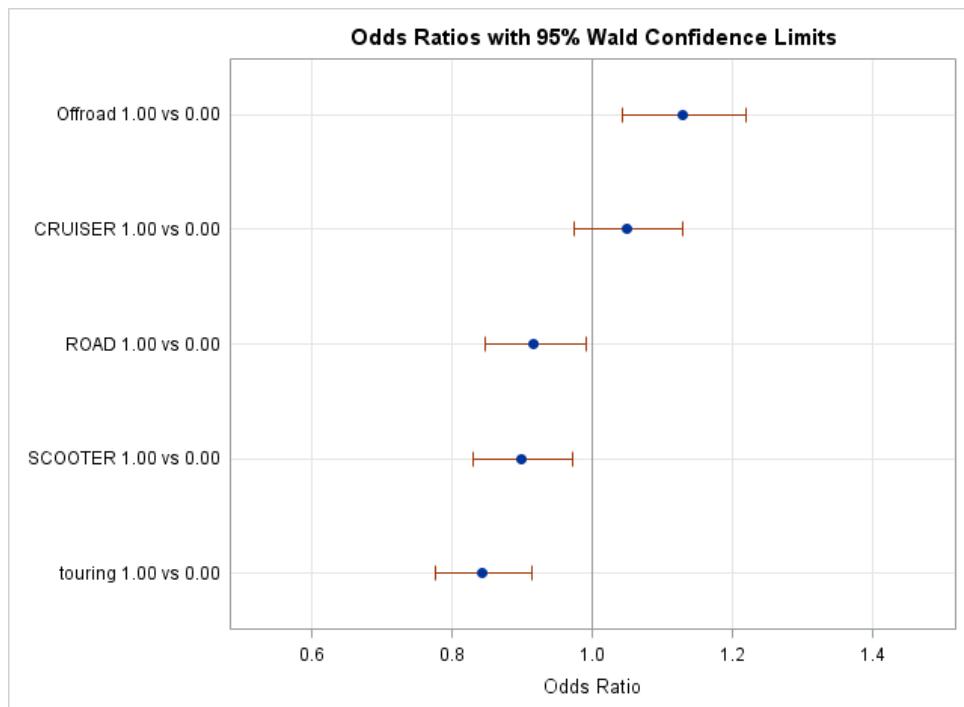


Figure 61 Odds of a more serious injury crash by Redbook type (2005 to 2014) using two different models of referencing

8.6 Frequency of Redbook types by jurisdiction

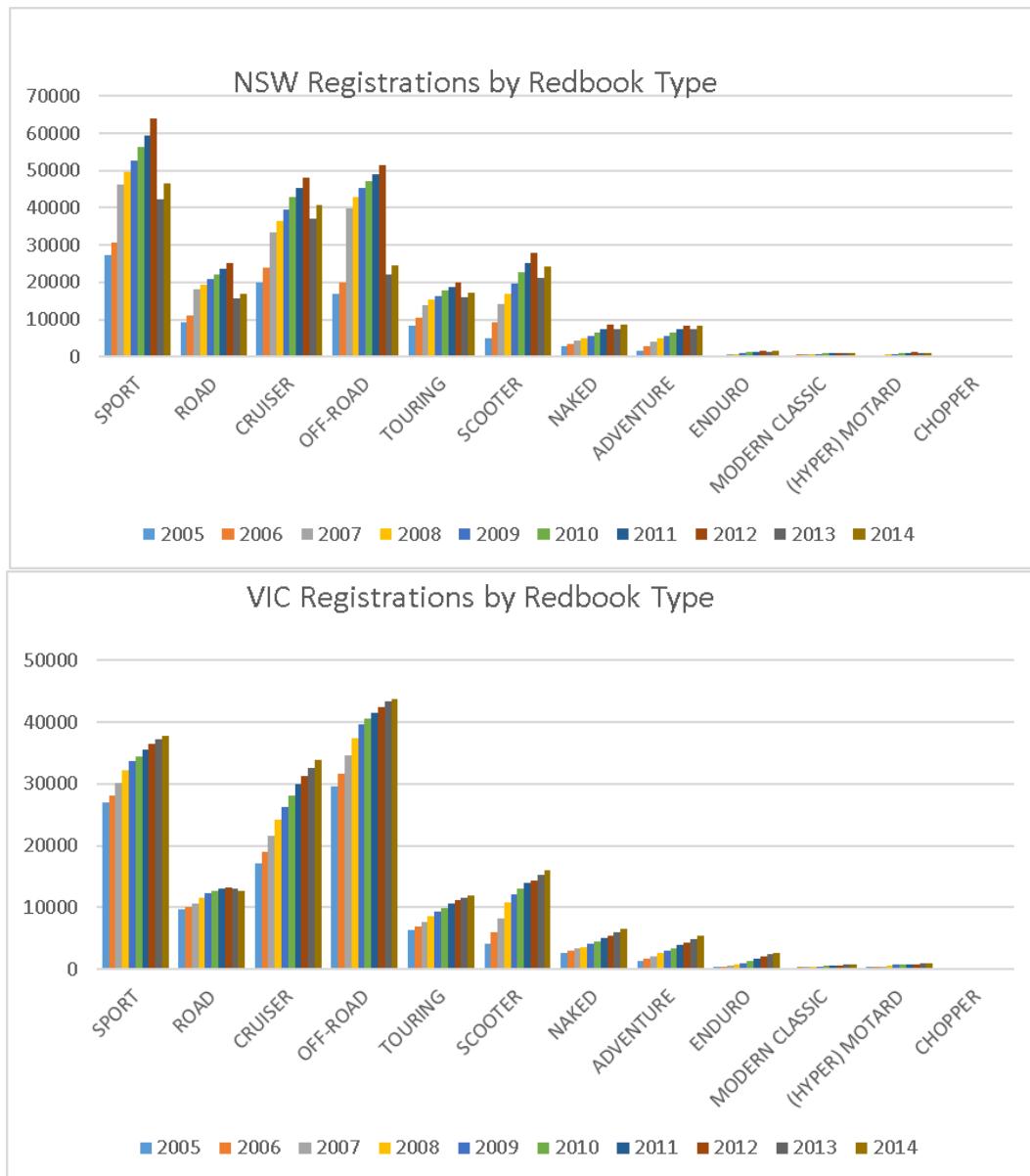


Figure 62 RVCS matched registration data (2005 to 2014) by Redbook type and Jurisdiction

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