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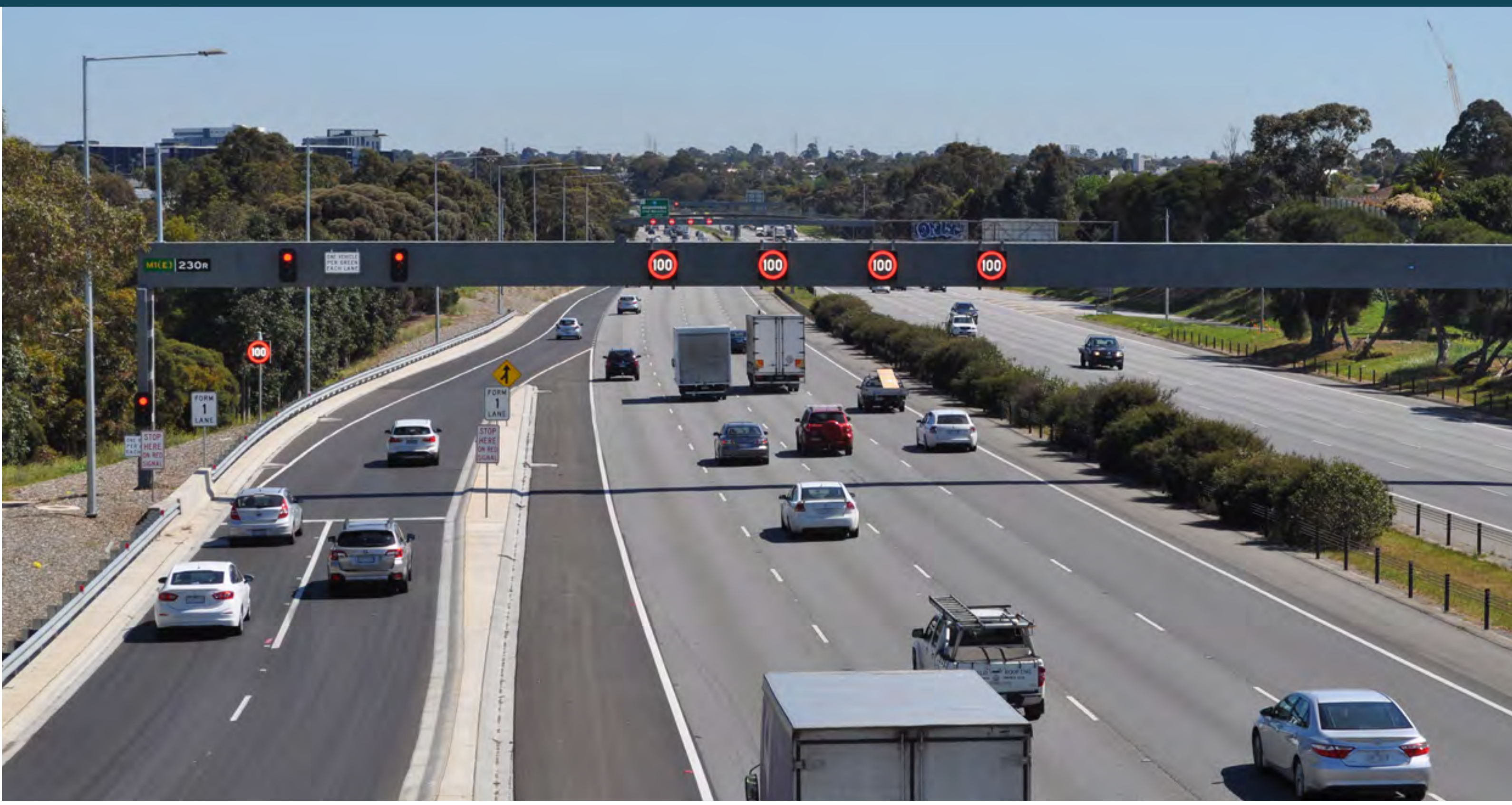
Journal of Road Safety



Peer-reviewed papers

Original Road Safety Research

MotoCAP wins prestigious international road safety award

The world-first safety rating system for motorcycle clothing, MotoCAP, won the prestigious Fédération Internationale de Motocyclisme (FIM) Road Safety Award in December 2019.

The MotoCAP - Motorcycle Clothing Assessment Program - aims to reduce the risk of serious injury or even death of motorcycle riders by providing them with the information to choose the right gear that provides the best protection in Australian conditions.

The MotoCAP safety rating scheme is designed to increase the use of effective motorcycle clothing by:

- promoting its benefits
- driving customer demand
- encouraging improved product supply.

MotoCAP consists of a consortium of government and private organisations across Australia and New Zealand. Visit the MotoCAP website for ratings and further details, **www.motocap.com.au**

NSW GOVERNMENT | TOWARDS ZERO

MOTOCAP

ABSTRACT SUBMISSIONS AND REGISTRATION NOW OPEN

MARK YOUR DIARY WITH THESE KEY DATES:

Abstract Submission Deadline: **10 February 2020**

Early Bird Registration Deadline: **31 July 2020**

2020 AUSTRALASIAN ROAD SAFETY CONFERENCE

Melbourne Convention & Exhibition Centre
16 – 18 September 2020

Towards Zero - A Fresh Approach

FOUNDING PARTNERS: ACRS Australasian College of Road Safety; Austroads

PLATINUM SPONSOR: Victoria State Government Department of Transport; Towards Zero; TAC

The Australasian College of Road Safety (ACRS) and Austroads invite you to attend the largest road safety-dedicated conference in the Southern Hemisphere. The 2020 Australasian Road Safety Conference (ARSC2020) will be held in Melbourne at the Melbourne Convention & Exhibition Centre from Wednesday 16 September to Friday 18 September 2020.

ARSC2020 will showcase the region's outstanding researchers, practitioners, policy-makers and industry spanning the range of road safety issues identified in the United Nations Decade of Action for Road Safety: Road Safety Management, Infrastructure, Safe Vehicles, User Behaviour, and Post-Crash Care.

ARSC2020 will bring with it a special focus on engaging all levels of government and community, from the city to the bush, to move "Towards Zero - A Fresh Approach". The comprehensive 3-day scientific program will showcase the latest research; education and policing programs; policies and management strategies; and technological developments in the field, together with national and international keynote speakers, oral and poster presentations, workshops and interactive symposia.

WHO SHOULD ATTEND?

ARSC2020 is expected to attract 500-700 delegates including researchers, policing and enforcement agencies, practitioners, policymakers, industry representatives, educators, and students working in the fields of behavioural science, education and training, emergency services, engineering and technology, health and rehabilitation, policing, justice and law enforcement, local, state and federal government, traffic management, and vehicle safety.

REGISTRATION NOW OPEN

ABSTRACT SUBMISSIONS NOW OPEN

Register Your Interest

To register your expression of interest as a delegate, speaker, sponsor or trade exhibitor, or for further information about the conference, please visit **www.australasianroadsafetyconference.com.au.** Additional enquiries should be directed to the Conference Secretariat, Premier Event Concepts on **(+61) 437 377 107** or **shanna@premiereventconcepts.com.au**

YOUR HOST CITY: MELBOURNE

Set on the shores of picturesque Port Phillip Bay, the southern-most city of mainland Australia is Melbourne; the capital city of Victoria where creativity and innovation come together to deliver great events, exciting places to explore and cutting-edge advancements that are globally acclaimed. As a major Australian gateway, Melbourne is easily accessible for international delegates and also easy to navigate once arrived. Perfect to explore on foot or via the extensive transport network, Melbourne invites delegates to discover its creative culture, expressed in its food, fashion, events, arts and music scene. Or for those wanting to explore further afield, the unique natural beauty of regional Victoria is just a short trip away.

www.australasianroadsafetyconference.com.au

Contents

Cover image

Casualty crash reductions on urban motorways may be achieved through Intelligent Transport Systems (ITS) strategies that minimise flow breakdown, including Variable Speed Limit (VSL) signs, integrated Lane Use Management System (LUMS) and real-time localised congestion warnings. See Original Road Safety Research article: Hovenden, E., Zurlinden, H. and Gaffney, J. (2020). "Safety on Heavily Trafficked Urban Motorways in Relation to Traffic State". *Journal of Road Safety*, 31(1), pages 51-65. Photo source: Department of Transport, Victoria.

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Subscriptions
All issues of this Journal are mailed to personal members or corporate delegates of the Australasian College of Road Safety. Organisations and persons who are not members of the College may subscribe to the Journal on payment of an annual subscription.

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Editorial Policy
The *Journal of Road safety (JRS)* is an international, scholarly, cross-disciplinary, peer-reviewed and open-access journal purely focused on road safety. The JRS accepts papers from any country or region and aims to publish a diverse range of high quality papers on road safety from researchers, policy makers and other road safety experts.

All papers submitted to the JRS undergo a peer-review process, unless the paper is submitted as a Contributed Article or *Correspondence (Letter to the Editor)*. Peer-review Papers and Contributed Articles can take the form of the following articles types: *Original Road Safety Research; Road Safety Data & Research Methods; Road Safety Policy & Practice; Road Safety Case Studies; Road Safety Evidence Review; Road Safety Media Review; Perspective on Road Safety*.

All submissions are assessed on the basis of quality and importance for advancing road safety, and decisions on the publication of the paper are based on the value of the contribution the paper makes in road safety. Once a paper is submitted, the Editor-in-Chief and/or Managing Editor initially review the submission. Authors are notified if their paper is judged to be outside of the JRS' scope or lacks originality or message that is important to the readers of the JRS.

Peer-review submissions that pass the initial screening process will be sent out to a minimum of three peer reviewers selected on the basis of expertise and prior work in the area. Additional peer reviewers may be called on at the discretion of the Editor(s), e.g. in the case of a disagreement between referees' opinions. The names of the reviewers are not disclosed to the authors. Each submission is peer-reviewed by a minimum of three experts in the field.

Based on the recommendations from the peer-reviewers, the Editor-in-Chief makes a decision, in consultation with the Managing Editor and/or Editorial Board when needed, to accept or reject a manuscript, or to request revisions from the author/s in response to the comments from the reviewer/s. Authors are informed of the decision after the first round of review. Revised submissions are sent out for a second round of review and authors are again notified of the decision based on the recommendations from the peer-reviewers.

Contributed Article submissions that pass the initial screening process will be reviewed in detail by the Managing Editor and an additional reviewer may be called on at the discretion of the Editor(s) or the paper may be subject to peer-review, e.g. in the case of contentious contents that need expert assessment. The Managing Editor makes a decision, in consultation with the Editor-in-Chief and/or Editorial Board when needed, to accept or reject a manuscript, or to request revisions from the author/s in response to the comments from the reviewer/s. The names of the reviewers are not disclosed to the authors. Authors are informed of the decision after the first round of review.

As a rule of thumb, manuscripts can undergo only one major revision. Any editorial decisions regarding manuscript acceptance by the Editor-in-Chief and Managing Editor are final and further discussions or communications will not be entered into in the case of a submission being rejected. For both peer-review and contributed articles, one or more of the reviewers may require a major revision or reject the paper because of content that may otherwise be of general interest to readers but is not at the level expected of a caliber of a scientific journal paper.

Author responsibility
Authors are responsible for complying with all the requirements (including Article formatting, References, Ethics in publishing, Originality & plagiarism, Author declaration) before submitting their papers. Authors must write entirely original works, and appropriately cite the work and/or words of others to ensure originality and avoidance of plagiarism. Authors of original road safety research articles should present an accurate account of the work performed as well as objective discussion of the findings and their significance. Submission of an article implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint), that it is not under consideration for publication elsewhere, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

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Editorial Board

From the President

In 1978, the National Highway Traffic Safety Administration in the United States of America took road safety to a new level when it started the New Car Assessment Programme (NCAP), testing vehicles for the level of protection provided to consumers in a frontal impact crash.

As the leading consumer organisations in road transport, automobile clubs began to see the massive potential safety benefits for their members. The establishment of the Australasian NCAP in 1992 was quickly followed by Japan NCAP, Euro NCAP and Korea NCAP, and more besides. Global NCAP is a world leading consumer advocacy body.

Three decades on, the consumer sentiment is clear – the release of five star safety ratings for tested vehicles is mundane. The release of a one star safety rating, such as occurred last year with the Jeep Wrangler, is outrageous.

Putting to one side issues which are always likely to occur between consumers, manufacturers, and regulators, a virtuous vehicle safety circle can be observed in high income countries. Consumers demand more safety, manufacturers deliver more safety, and regulators lock in those safety gains for future generations.

The safety lesson is clear. Objective safety information provided in easily understood form is welcomed by consumers, and they will act on that information.

In my last message, I referenced the policy of the Australasian College of Road Safety for 2030 targets to reduce fatalities and serious injuries by 50%. This is challenging, and achievable, and needs to be followed up by 50% reductions for the following two decades if Transport and Infrastructure Ministers' goal of zero by 2050 is to be credibly progressed.

How will this be done? We know that there is major investment required in management systems and leadership.

Major advances will also be needed in infrastructure safety, vehicle safety, user compliance, and speed management, along with the continual improvement of trauma management. Good governance disciplines around transparency and reporting will also be vital.

Recognising the progress being made in vehicles, consumer organisations started down a long path of improving the safety of roads, beginning with the European Road Assessment Program (RAP) in 1999, followed by AusRAP, KiwiRAP etc. There has been some spectacular progress, with iRAP and safety star ratings for roads now embedded in the global road safety consciousness. The United Nations uses safety star ratings as one of 12 voluntary road safety performance targets for countries which are serious about tackling their road safety problem.

In Australia, progress has been painfully slow. Generally not prepared to accept AusRAP as a performance measure, and simply antagonistic in at least one case, roads and traffic authorities began work on their own safety rating system – the Australian National Risk Assessment Model.

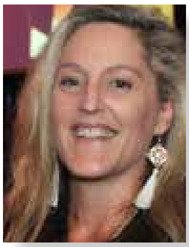
A decade has passed. Consumers in Australia still have no objective, easily understood, uniform public information about the safety of the roads they use. In 2017, the College called for the publication of safety star ratings on the national road network to be a condition for any Commonwealth investment in the network. This is public safety information, held by public agencies in the States and Territories. Why is this information not being prepared and made available for public review?

Star rating has worked spectacularly well in vehicle safety because it makes transparent essential public safety information. This would be particularly valuable for roads in regional communities where the fatality rates are so high. Respectful, strategic conversations are needed in regional communities about the inherent safety of the current infrastructure, the safety of the speeds that are being travelled, and the options and costs associated with providing a safe road environment. Regional communities deserve this respect.

New Zealand has had its own issues in this area and has not released safety star ratings for some years. Its recently released Road to Zero strategy has a very important indicator: the percentage of travel on the rural network that has a 3-star equivalent rating or better. A target to 2030 should be set, but it is a start. Perhaps Australia can do better. Release of vital public safety information is essential. We won't reach zero without it.

Martin Small
ACRS President

From the CEO



A very Happy New Year to our many members and supporters, and thank you for joining us on our ongoing journey to support best road trauma reduction outcomes possible – we are thrilled to have you with us!

2020 has seen the ACRS off to another flying start with a suite of exciting projects already underway. A selection of these projects is as follows:

- **Major global road safety event in Stockholm (February 2020)** – Several College representatives will be attending the 3rd *High Level Ministerial Road Safety Conference in Stockholm, Sweden*. During this event the ARSC2019 Declaration - which was signed by many of you who attended our ARSC2019 conference in Adelaide last September - will be presented by our highest ranking Australian federal parliamentarian to the World Health Organisation, as a symbol of our collective support for global goals and leadership.
- **Australian Federal Government Grants** – We are fortunate recipients of the following federal grants to support both our international outreach work plus our major annual conference which has quickly become recognised as the largest road-safety dedicated annual event in the southern hemisphere.
    - International Outreach Chapter Grant ($400,000 over 2019-2021) – a primary aim of our delegation to Sweden is to continue discussions with key current and potential partners and experts to guide and support us in our outreach work to Low- and Middle-Income Countries (LMIC's). I will look forward to sharing more news around this exciting project with you over coming updates.
    - Conference sponsorship Grant ($200,000 over 2020-2023) – this funding locks in continued support from the federal government for the amount of $50,000 per annum for each of our next 4 ARSC conferences – Melbourne (2020), Christchurch NZ (2021), Gold Coast (2022) and Darwin (2023). This support includes a Gold Sponsorship plus funding to support multiple LMIC Scholarships.
- **ARSC2020** – Preparations for our 2020 Australasian Road Safety Conference to be held in Melbourne 16-18 September 2020 are now well underway, thanks to the assistance of our co-Chairs Mr Chris Brennan (Manager Road Safety Planning, Victorian Department of Transport) and Dr Jeff Potter (Principal Safety Policy Advisor, National Transport Commission). We have a fantastic team in place as our ARSC2020 Organising Committee (formed with the ACRS Victorian Chapter as the

core), plus the multiple sub committees - Scientific, Sponsorship, Social and International - which enlist the assistance of literally hundreds of you to ensure we bring you the best of the best research, projects and examples of outstanding teamwork and practice to help us in our work. Please watch this space https://australasianroadsafetyconference.com.au/ and we'll look forward to you joining us at our region's premier road safety event in Melbourne.

- **Journal Re-brand** - Members will note our *Journal of the Australasian College of Road Safety (JACRS)* has been re-branded as the *Journal of Road Safety (JRS)*. This change ensures our brand is strengthened to align with the growing international outreach of the organisation.
- **New ACRS Website** http://www.acrs.org.au/ - You will note our website has had a complete redevelopment and is now much more modern and accessible as a result. We aim to continue this enhancement of our communications channels and are currently recruiting for our first ever Communications Manager who will lead us onwards and upwards towards the next phase of our communications improvements.
- **New Journal Website** – Our new stand-alone JRS website is currently in progress and we aim to release this publicly shortly, perhaps in time for next edition of the JRS in May. This dedicated website for our premier publication will ensure the profile of the JRS is lifted to even newer heights!
- **Strategic Review & Constitutional Updates** – We are very excited to be working on implementing the strategic changes that were suggested and supported by our executive leaders, staff, members and non-members during the 2018/2019 ACRS Strategic Review. These changes have been approved by our Executive Committee in order to consolidate the significant progress we've made over the last decade, and importantly to provide a solid footing to enable further growth of our organisation. All of these changes are of course designed with our primary purpose in mind - to support best road trauma reduction outcomes possible. These improvements include a significant update to the College's Constitution which will involve a rewrite of our aims and objectives, plus allow us to strengthen our operational framework including, for example, the necessary updates to allow us to move beyond providing a Jan-Dec membership year which brings with it the issue of pro-rata payments.
- **Operational Expansion** – We continue to support the College's organisational growth with a broadening of our expertise base and increased staffing levels. When I first commenced employment at the College as Executive Officer in 2011, we had a workforce of 3 part-timers providing an approximately 1.8 full-time equivalent resource. We also had a governing council (our Executive Committee) of 12 volunteers. Today we have a staff of 9 and are currently recruiting for 2 brand new positions of Operations Manager and Communications Manager. In addition to our operational staff we now have an Executive Committee of 18 volunteers spread across Australasia. We are also of course proud to have 25 awarded Fellows who I often call on for their expertise and advice. These Fellows are spread across the globe, with many embedded at and operating at very senior levels across all sectors. We are rapidly outgrowing our small office space and will shortly need to find a larger home, with associated increased IT capability. We are moving ahead with new finance and IT systems and technologies, and look forward to supporting further growth as a result. We will also be looking to further support our regional Chapters – including of course our new International Outreach Chapter. Very exciting times!

I look forward to keeping you all updated with progress on these and many other projects throughout the year and beyond – watch this ever-evolving space!

As always, stay safe, and best wishes,

Claire Howe
Chief Executive Officer - ACR

ACRS Chapter reports

Chapter reports were sought from all Chapter Representatives. We greatly appreciate the reports we received from ACT, SA and the NZ.

Australian Capital Territory (ACT) and Region

The two main areas of focus for the ACT Chapter in the second half of 2019 were

- Wildlife Crashes – This is an increasing issue as the number of serious injury crashes involving wildlife (especially Kangaroos, but increasingly Deer, brumbies, etc) and the involvement of vulnerable road users creates concern in the ACT and surrounding region of NSW.

Following a successful forum and subsequent presentations at NSW Health and the ARSC2019, the Chapter is forming an ongoing working group with interested parties from ACT, NSW and interstate to take the issue forward.

- Electric scooters and similar devices – This Forum undertaken on behalf of the ACT Government has resulted in the Government's introduction of new regulations for the use of these devices from January 2020.

More information is available at: http://www.justice.act.gov.au/news/view/1794/title/e-scooters-and-other-similar-devices

The issue is complex and developing as the scope and range of devices continues to grow quickly. The potential interaction, particularly between the more vulnerable road users with significant differences in speed and the substantial forces involving the people in any impact, needs continuing oversight.

The Chapter will continue its interest in the development of this regulation and the experience with these new devices in the community.

Driver licensing

Upgraded requirements for learner and provisional drivers were also introduced on 1 January 2020. The Chapter was involved in the public community forum held to consider revised arrangements.

2020 Program

In 2020 the Chapter proposes to focus on Older drivers again; Speeding and fatigue (especially for tradies); Roads as workplaces; and Graduated License changes.

ACT Chapter Chair and Secretary
Mr Eric Chalmers & Mr Keith Wheatley

South Australia (SA)

SA Chapter Committee Executive

After many years as the Chapter Chair, Jeremy Woolley stood down at a recent members' meeting. Jeremy was thanked for his service, particularly as his responsibilities and workload increased at the Centre for Automotive Safety Research and as co-chair of the Federal Enquiry. The committee executive now comprises: Jamie Mackenzie (Chair), Philip Blake (Secretary) and Jeff Dutschke (Treasurer). The Deputy Chair remains vacant.

Urban Planning and Road Safety Lunchtime Seminar, 9 December 2019.

The South Australian Chapter hosted over 30 attendees to hear about urban planning focusing on road safety at a lunchtime seminar held on 9 December. There was much interest in the two presentations. Natalya Bourjenko (Intermethod) and Scott Elaurant (Six Cats Consulting) presented a good overview of the safe systems approach applied to the urban environment and focused on challenging some longstanding urban road design standards and practices using the latest internationally. Hugh Gallagher (City of Adelaide) presented a case study of the Frome Street separated bikeway. Attendees asked many questions after each presentation, particularly about cyclists and other vulnerable road users.

The next lunchtime event will be in late February on recent research by the Centre for Automotive Safety Research.

SA Chapter Chair and Secretary

Jamie MacKenzie and Phil Blake

New Zealand (NZ)

Planning for the 2021 Australasian Road Safety Conference has begun. The conference will be held in Christchurch from 28 September - 1 October 2021 at the Christchurch Convention Centre Te Pae. Sponsorship has been sought from the NZ Government for the conference, with Robyn Gardener and President Martin Small presenting the request to the Associate Minister of Transport, Hon Julie Anne Genter.

NZ Chapter Co-Chairs
Dr Rebecca Brookland and Mr Paul Durdin

ACRS News

A new name for our premier publication: The "Journal of Road Safety" + Calling for LMIC Author Mentors & Mentees

A huge thank you to ACRS members, authors, peer-reviewers and readers who have made contributions and supported the growth of ***Journal of the Australasian College of Road Safety (JACRS)***. The ACRS' Journal has evolved over the years but with a continued focus on improving road safety from its birth. In order to reflect our increasingly international standing and influence in road safety, our Journal will be published under the new title **Journal of Road Safety (JRS)** [ISSN 2652-4252 (Online); ISSN 2652-4260 (Print); DOI:10.33492/JRS] from February 2020.

The Journal of Road Safety (JRS) continues to be committed to its roles beyond the publication of peer reviewed papers and contributed articles. Messages from the President and the CEO, Chapter reports and ACRS News will continue to be an integral part of the Journal for the benefit of ACRS members.

We continue to welcome your submissions online: https://www.editorialmanager.com/jacrs/default.aspx

Author Instructions and Word 2010 / Word 97 – 2003 Template to guide your writing are available from the ACRS website: https://acrs.org.au/publications/journal-contacts-instructions/

The Journal of Road Safety (JRS) is also excited to announce a new program with the support of the Australian Department of Infrastructure, Transport, Cities and Regional Development. We will be providing capacity development support for road safety professionals from low and middle income countries (LMICs) through a mentorship program for scientific journal paper-writing.

This is an exciting opportunity for LMIC authors to further develop their capacity and contribute to the improvement of road safety in LMICs, which suffer 93% of global road crash deaths. If you are interested to become a mentor or mentee please see details and sign up online: https://acrs.org.au/publications/journals/jrs-mentorship-program/

We look forward to further growing the JRS with you and bringing you a valuable scientific journal dedicated to road safety.

2020 Australasian Road Safety Conference "Towards Zero - A Fresh Approach" – Call For Abstracts Open

The ARSC Conference has become the largest road safety-dedicated conference in the Southern Hemisphere. ARSC2020 will be held in Melbourne at the Melbourne Convention and Exhibition Centre from Wednesday to Friday 16-18 September 2020. It is expected to attract between 600-800 delegates including researchers, policing and enforcement agencies, practitioners, policymakers, industry representatives, educators, and students working in the fields of behavioural science, education and training, emergency services, engineering and technology, health and rehabilitation, policing, justice and law enforcement, local, state and federal government, traffic management, and vehicle safety.

With a theme of **"Towards Zero: A Fresh Approach!"**, ARSC2020 will showcase the regions' outstanding researchers, practitioners, policy-makers and industry spanning the plethora of road safety issues identified in the United Nations Decade of Action for Road Safety.

The comprehensive 3-day scientific program will bring a special focus on engaging all levels of government and community, from the city to the bush, to move Towards Zero.

You are invited to submit an Extended Abstract to the Australasian Road Safety Conference ARSC2020: https://australasianroadsafetyconference.com.au/submissions/abstracts/

Welcome Message from our co-Chairs & co-Host organisations: "It's not through luck alone that Melbourne has consistently ranked as one of the world's most liveable cities. A thriving city of over 6.4 million people, our population has grown faster than any other Australian city over the past 10 years. If trends continue as predicted, Melbourne will overtake Sydney as Australia's largest city by 2030.

As our cities grow, the way we choose to get around is undergoing its own evolution. In an age dominated by technology and choice, transportation is fundamental to the liveability of our great city. Transport is also critical to our rural and regional communities by supporting social inclusion, access to goods and services and employment.

For decades now, Victoria has been at the forefront of significant road safety reforms, both nationally and internationally, by being open to fresh approaches to drive the road toll down towards zero.

World-leading initiatives such as mandatory seatbelt laws, random breath testing and roadside drug screening have helped make the roads safer for everyone, both in Victoria and around the world, where these and other ideas have been adopted and refined.

Now, as we begin a new decade, we are again seeking the fresh approaches and new ideas that will position Australia to achieve its vision zero target by 2050, help drive New Zealand further along their Road To Zero and improve road safety throughout the Asia/Pacific region.

Join us in Melbourne in September 2020 to build on the wonderful advancements made during the Decade of Action for Road Safety and showcase your fresh approach as we embark on a brand new decade.

We look forward to seeing you in Melbourne!"

Diary

19-20 February 2020
3rd Global Ministerial Conference on Road Safety
https://www.roadsafetysweden.com/
Stockholm, Sweden

27-30 April 2020
Rethinking Transport: Towards Clean and Inclusive Mobility (TRA 2020)
https://traconference.eu/
Helsinki, Finland

5-7 May 2020
2nd United Nations Global Sustainable Transport Conference
https://sustainabledevelopment.un.org/transport2020
Beijing, China

12-14 May
Safer Roads 2020 Conference,
http://saferroads2020.atssa.com/
Virginia, USA

15-18 June
The 30th CARSP Conference and the 14th PRI World Congress
http://www.carsp.ca/carsp-conference/2020-joint-conference/
Montréal, Canada

25-27 August
7th ICTTP
https://icttp2020.se/
Gothenburg, Sweden

16-18 September 2020
Australasian Road Safety Conference 2020
www.australasianroadsafetyconference.com.au
Melbourne, Australia

27-29 September
International Alcohol Interlock Symposium
http://interlocksymposium.com/
Oslo, Norway

12-14 October
7th International DDI Conference
https://ddi2020.sciencesconf.org
Lyon, France

4-6 November
9th International Cycling Safety Conference
http://www.icsc-2020.net/app/netattm/attendee/page/92553
Lund, Sweden

Motorcycle crashes resulting in hospital admissions in South Australia: Crash characteristics and injury patterns

James Thompson[1], Matthew Baldock[1] and Tori Lindsay[1]

[1]*Centre for Automotive Safety Research, University of Adelaide, Adelaide, Australia.*

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This peer-reviewed paper was first presented as an Extended Abstract and Oral Presentation at the 2019 Australasian Road Safety Conference (ARSC2019) held in Adelaide, Australia and first published in the ARSC2019 Proceedings in the form of an Extended Abstract. It was expanded into a 'Full Paper' and underwent further peer-review by three independent experts in the field. It is being reproduced here with the kind permission of the authors and is now only available in this edition of the JACRS.

Key Findings

- 763 motorcyclists' hospital records linked to crash data and forensic blood tests;
- Crash characteristics and injuries examined and compared to 1617 car drivers;
- Motorcyclists were younger, more likely men and learners, less likely over .05 BAC;
- More likely crash in 50 and 80km/h area, daylight, weekends, dry roads and weather;
- Higher severity, longer in hospital, more likely injured in multiple body regions.

Abstract

Motorcycle riders have a high risk of serious injury if they crash. To assist with identification of countermeasures, the present study examined records from the Royal Adelaide Hospital (RAH) in South Australia for 763 motorcyclists (including scooter riders) admitted between January 2008 and November 2010 and between April 2014 and December 2016. Records were linked with police-reported crash data and results of forensic blood tests for alcohol and drugs. When compared with 1617 car drivers admitted to the RAH over the same periods, motorcyclists were younger, were more commonly male, more likely to hold a learner permit, less likely to hold a provisional licence, less likely to be over the legal alcohol limit and less likely to be at-fault in multiple vehicle crashes. Their crashes were more likely to be single vehicle crashes (specifically roll over, left road – out of control and hit object/animal/pedestrian on road crashes) and were more common on weekends, during the afternoon, on sloping roads, on curved roads, on roads with speed limits of 50 and 80 km/h, during daylight hours, in dry weather and on dry roads. They had a higher severity of injury than car drivers, spent longer in hospital, and were more likely to sustain injuries to multiple body regions. Linear regression showed that older age, higher blood alcohol concentration and higher speed limit increased injury severity for motorcyclists. Based on present findings, motorcycling safety can be improved through countermeasures related to Graduated Licensing Systems, infrastructure, motorcycle technology and protective clothing.

Keywords

Motorcycle, Scooter, Crash Characteristics, Injury Severity, Hospital Data, Countermeasures

Introduction

Riding a motorcycle or scooter is a high-risk mode of transportation, with considerably higher rates of serious or fatal injuries than other road users (Johnston, Brooks, & Savage, 2008; Keall & Newstead, 2012; Van Eslande & Elvik, 2012; Lin & Kraus, 2009). Keall and Newstead (2012) found that the risk of injury is greater for motorcyclists than for occupants of small cars in New Zealand, while Van Eslande and Elvik (2012) reported that in Norway motorcycles and cars have similar crash rates but that serious injuries occur with greater frequency for motorcyclists. In South Australia, motorcyclists account for a substantial proportion of the State's road trauma, comprising 17% of serious injuries and 12% of fatalities between 2012 and 2016 (Baldock, 2018).

The high injury rates for motorcyclists have prompted a number of studies examining injury patterns among crashed motorcyclists. In a review of literature regarding motorcycle crashes and injuries, Lin and Kraus (2009) found that riders often sustain multiple injuries in a crash, with the most common site being the lower extremities. The most frequent injury in fatal crashes was to the head (contributing to about 50% of motorcycle deaths) followed by injury to the chest and abdominal areas (contributing to between 7% and 25%). Forman et al. (2012) examined hospital discharge data for 12,994 riders in eight European countries. Injuries to a lower extremity (26%) and upper extremity (20%) were most common, followed by traumatic brain injuries (18.5%).

Other studies have found that spinal injuries tend to occur more frequently with single vehicle crashes, particularly those involving collisions with fixed objects (Zilkipli et al., 2012); that thoracic injuries are common following collisions with barriers (Bambach, Grzebieta, & McIntosh, 2012; Daniello & Gabler, 2012); and that fatal crashes are associated with older riders, collisions with trees, night riding, curved roads and local roads (Huang & Lai, 2011). A higher risk of injury has been linked to failure to wear protective clothing (de Rome et al., 2011; de Rome, Ivers, et al., 2012), and right angle or turn across path crashes, speeding and alcohol use (Rifaat, Tay, & De Barros, 2012).

The present study obtained data from the Royal Adelaide Hospital (RAH) in South Australia for two time periods (January 2008 to November 2010; April 2014 to December 2016). These data were linked with police-reported crash data and the results of blood tests for alcohol and drugs. The aim was to undertake an examination of crashes in which a rider of a motorcycle or scooter was injured, in terms of rider characteristics, crash characteristics, injury patterns and injury severity, and make comparisons to crashes in which a car driver was injured. It was decided that the comparison sample would be comprised of crashes involving car drivers as, firstly, with regard to injury patterns and severity, cars offer vehicular protection while motorcycles do not, and this comparison would potentially identify injury patterns unique to motorcyclists. Secondly, with regard to rider and crash characteristics, cars are the most common vehicles both on the road and involved in crashes, and comparisons to car crashes would identify what is unique about both the people who ride motorcycles and the crashes they are involved in.

Methods

Data

Data were collected for road users who were injured in a crash and were admitted (four hours or more) to the RAH over two time periods, January 2008 to November 2010 and April 2014 to December 2016. These data included 375 crash-involved motorcyclists for the 2008 to 2010 period (34 scooter and 341 motorcycle) and 388 for the 2014 to 2016 period (36 scooter and 352 motorcycle). There were also 803 crash-involved car drivers (and car derivatives such as utility vehicles, station wagons and sports utility vehicles) for the 2008 to 2010 period and 814 for the 2014 to 2016 period for comparison. Data included medical assessments and interventions undertaken during hospitalisation, police-reported crash information, and forensic tests for alcohol and drugs. One of the authors (Tori Lindsay) attended the RAH to collect the hospital data and linked these data to police-reported data and alcohol and drug tests through details of the crash (e.g. date) and the participants (e.g. date of birth, driver licence number) and vehicles (e.g. make, model, registration number).

Medical data

The medical data included ambulance records, emergency department records, and hospital in-patient records. Ambulance records included information about the crash gathered at the scene and the initial care given to the injured participants. Emergency department records included injury surveys. Hospital in-patient records included patient demographics, injury and medical intervention information, and discharge details.

Injuries were coded according to the Abbreviated Injury Scale (AIS), which was developed by the Association for the Advancement of Automotive Medicine to classify the threat to life associated with injuries. Each separate injury is given a score on a scale from one (minor) to six (currently untreatable) and is categorised by the body region in which it occurred (six regions: abdomen, chest, external, extremities, face and head/neck). A maximum AIS (MAIS) was also coded for the injury with the highest AIS score within each separate body region, as a person may receive a number of separate injuries to a specific region.

Each injured crash participant's AIS scores were converted to an Injury Severity Score (ISS) to give an overall measure of injury severity. ISS is calculated by taking the three most severely injured body regions, squaring the number given to the most severe injury and summing these numbers. Only numbers one to five are used, giving a maximum ISS of 75. If any injury has an AIS score of six (untreatable), ISS is automatically set to the maximum 75.

Police-reported crash data

Police-reported crash data were obtained from the Traffic Accident Reporting System (TARS). TARS data included: date, time, day of week and location (metropolitan or rural) of the crash; vehicle type (e.g. motorcycle, car); licence types of crash participants (full, learner, provisional, probationary, unlicensed or disqualified); description of the crash; crash type (single or multiple vehicle); vertical alignment (slope or level), horizontal alignment (curved or straight), road surface (unsealed or sealed) and speed limit at the crash location; light conditions (day or night), weather conditions (raining or dry) and road conditions (wet or dry) at the time of the crash; and the injury status of those involved. At-fault status (yes or no) for the drivers or riders involved is also recorded in TARS.

Blood tests for alcohol and drugs

Since 1972, drivers, motorcycle riders, vehicle occupants and pedestrians over the age of 14 years, who present to hospital as a result of a crash, have been required to undergo testing for blood alcohol concentration (BAC) in South Australia. Since July 2008, road users have also been screened for three proscribed drugs: Methamphetamine, Delta-9-Tetrahydrocannabinol (THC) and 3,4-Methylenedioxymethamphetamine (MDMA). Blood samples (taken within eight hours following the crash) are tested by the South Australian Forensic Science Centre. These results were made available for the present study.

Analyses

Sample characteristics (age, gender, licence type, helmet use, blood test results, and at-fault status), crash characteristics (day of week, time of day, crash location, crash type, vertical and horizontal alignment of the road, road surface, speed limit, and light, weather and road conditions), and injury patterns and severity (length of hospitalisation, ISS, AIS) were examined for motorcycle riders, and comparisons made to car drivers. Frequency counts, means, chi-square tests and independent-samples t-tests were used. Additionally, linear regression was used to examine whether several independent variables (age, gender, crash location, BAC level, drug test result, road surface, type of crash and speed limit) predict injury severity (ISS – dependent variable) for motorcyclists. For all analyses, an alpha level of 0.05 was used for statistical significance.

Results

Sample Characteristics

The age and gender distribution of the total sample of crash-involved motorcycle riders (both time periods combined) is shown in Table 1. Those aged from 20 to 59 comprised 84.4% of the crash-involved population; females comprised just 6.9%. Car drivers are also shown, with a greater representation of females (41.9%) and people aged over 60 (25.9% compared to 8.4% of motorcyclists). The mean age of 39.3 years (*SD*=14.7) for motorcyclists was significantly lower than the mean of 44.9 years (*SD*=20.9) for car drivers ($t(2378)=6.7, p<.001$).

Five hundred and eighty-one riders held a full licence (78.8% of known), 43 held a learner permit (5.8%), 70 held a provisional licence (9.5%), seven held a probationary licence[1] (0.9%), 28 were unlicensed (3.8%), and eight had been disqualified from driving (1.1%). Licence status was unknown for 87 motorcyclists. In comparison, 1,253 car drivers held a full licence (80.1% of known), 27 held a learner permit (1.7%), 203 held a provisional licence (13.0%), 11 held a probationary licence (0.7%), 58 were unlicensed (3.7%), and 13 were disqualified (0.8%). Licence status was unknown for 52 drivers. A statistically significant difference ($\chi^2_{(5)}=33.8, p<.001$) was found between these distributions, with a larger proportion of crash-involved motorcyclists holding a learner permit and smaller proportion holding a provisional licence.

Of the 608 riders for whom BAC was known, 51 (8.4%) were above the legal limit of 0.05g/100ml. Of the 1360 drivers for whom BAC was known, 274 (20.1%) were above the legal limit. These numbers included two riders and eight drivers with a positive BAC below 0.05 who held provisional licences only and were required to have a BAC of zero. This difference was statistically significant ($\chi^2_{(1)}=42.1, p<.001$). Of the 410 riders for whom drug status was known, 77 (18.8%) were positive. Thirteen of the 77 also had a BAC over 0.05. Of the 928 car drivers for whom drug status was known, 149 (16.1%) screened positive. Thirty-three of the 149 also had a BAC above 0.05. The small apparent difference between motorcyclists and drivers in the likelihood of testing positive to a proscribed drug was not statistically significant ($\chi^2_{(1)}=1.5, p=.220$).

Five hundred and eleven (77.7% of known) motorcyclists were found to be at-fault for their crash, while 147 (22.3%) were not at-fault, and at-fault status was unknown for 105. In comparison, 1232 (76.5% of known) drivers were at-fault, while 378 (23.5%) were not at-fault, and at-fault status was unknown for 7. The small difference in the distributions was not statistically significant ($\chi^2_{(1)}=0.3$, p=.560). However, when at-fault status was examined in multiple vehicle crashes only (single vehicle crashes removed), 40.6% of motorcyclists were at-fault compared 56.1% of car drivers. This difference was statistically significant ($\chi^2_{(1)}=23.6$, p<.001), indicating that motorcyclists are less likely to be at-fault in crashes involving several vehicles.

There were 708 motorcyclists wearing a helmet (98.3% of known) at the time of the crash, while helmet status was unknown for 43. Twelve riders were not wearing a helmet

Table 1. Age and gender of crash-involved motorcyclists compared to crash-involved drivers of cars

	Motorcyclists			Drivers of cars		
Age category	**Male % (*n*=710)**	**Female % (*n*=53)**	**Total % (*n*=763)**	**Male % (*n*=939)**	**Female % (*n*=678)**	**Total % (*n*=1617)**
16-19	7.2	7.5	7.2	9.5	8.1	9.0
20-29	24.9	24.5	24.9	20.8	23.9	22.1
30-39	19.9	18.9	19.8	17.7	13.9	16.1
40-49	20.0	22.6	20.2	16.5	13.3	15.2
50-59	19.2	24.5	19.5	10.9	13.3	11.9
60-69	6.2	1.9	5.9	8.1	10.5	9.1
70-79	2.3	0.0	2.1	7.7	9.9	8.6
80+	0.4	0.0	0.4	8.9	7.2	8.2
Total	100.0	100.0	100.0	100.0	100.0	100.0

and an inspection of these cases revealed that eight were above 0.05 BAC and four tested positive to THC.

Comparing Characteristics of Crashes Involving Motorcyclists and Car Drivers

Table 2 compares crashes involving motorcyclists to those involving car drivers on a number of variables. The crashes of motorcyclists were overrepresented on weekends, during the afternoon, in single vehicle crashes, on sloping roads, on curved roads, on roads with speed limits of 50 and 80 km/h, during daylight hours, in dry weather and on dry roads.

Greater information for crash type was available for the 2014 to 2016 data (crashes only classified as single or multiple vehicle for 2008 to 2010 data). There were 22 crashes involving motorcyclists for the 2014 to 2016 data that were side swipe crashes (5.8% of known), 101 roll over (26.7%), 38 right turn (10.1%), 54 right angle (14.3%), 38 rear end (10.1%), 14 left road – out of control (3.7%), 16 hit object/animal/pedestrian on road (4.2%), 16 head on (4.2%), and 79 hit fixed object/parked vehicle (20.9%). In comparison, there were 36 crashes involving car drivers for the 2014 to 2016 data that were side swipe crashes (4.4% of known), 48 roll over (5.9%), 79 right turn (9.7%), 154 right angle (19.0%), 92 rear end (11.3%), 7 left road – out of control (0.9%), 6 hit object/animal on road (0.7%), 81 head on (10.0%), and 308 hit fixed object/parked vehicle (38.0%). A statistically significant difference ($\chi^2_{(8)}$=156.1, p<.001) was found between these distributions. Roll over, left road – out of control and hit object/animal/pedestrian on road crashes were more common for motorcyclists, while right angle, head on and hit fixed object/parked vehicle crashes were more common for car drivers.

Examining injury patterns and severity of crashed motorcyclists

Table 3 shows the distribution of length of hospitalisation (in days) for motorcyclists and drivers. This table only includes those who were hospitalised, so it takes no account of the proportion of persons involved in injury crashes who were not injured severely enough themselves to attend hospital. Also, cases in which the motorcyclist or driver died after a period of hospitalisation were excluded. The most common length of hospitalisation for motorcyclists was between one and five days (40.1%). Drivers were more likely to require less than one day of hospitalisation (34.8% versus 17.3%), while motorcyclists were more likely to require between six and ten days (16.9% versus 11.9%) and between 11 and 15 (10.7% versus 6.1%) days. The difference between these two distributions was statistically significant ($\chi^2_{(8)}$=91.4, p<.001).

The hospital data did not include AIS scoring of injuries for car drivers for the 2008 to 2010 period. Consequently, only data from the 2014 to 2016 period were used for the purposes of comparing ISS between motorcyclists and drivers. The mean ISS of 9.2 (*SD*=7.8) for motorcyclists was statistically significantly higher than the mean of 6.4 (*SD*=7.8) for drivers (t(1192)=5.7, p<.001).

ISS could be examined according to additional categories of crash type for the 2014 to 2016 data for motorcyclists (as mentioned earlier crashes were only classified as single or multiple vehicle for the 2008 to 2010 data). The mean ISS for each type was: side swipe = 9.8 (*SD*=6.7), roll over = 7.7 (*SD*=6.7), right turn = 8.8 (*SD*=7.8), right angle = 7.3 (*SD*=6.1), rear end = 9.6 (*SD*=7.4), left road – out of control

Table 2. Characteristics of crashes involving injured motorcyclists compared to injured car drivers

Variable	Test statistic	Nature of difference
Day of week	$\chi^2_{(6)}$=25.1, p<.001*	Motorcycle crashes more common on weekends (39 vs 29%)
Time of day	$\chi^2_{(3)}$=49.5, p<.001*	Motorcycle crashes more common during the afternoon (50 vs 39%), car crashes between midnight and 6am (5 vs 13%)
Crash location	$\chi^2_{(1)}$=2.7, p=.103	No difference, metro or rural (50-50% vs 54-46%)
Single/multiple vehicle	$\chi^2_{(1)}$=5.0, p=.025*	Motorcycle crashes more commonly single vehicle (53 vs 48%)
Vertical alignment	$\chi^2_{(3)}$=80.3, p<.001*	Motorcycle crashes more common on sloping roads (23 vs 9%)
Horizontal alignment	$\chi^2_{(1)}$=25.7, p<.001*	Motorcycle crashes more common on curved roads (32 vs 22%)
Road surface	$\chi^2_{(1)}$<0.1, p=.872	No difference, sealed or unsealed (96% sealed for both groups)
Speed limit	$\chi^2_{(7)}$=58.3, p<.001*	Motorcycle crashes more common on roads with speed limits of 50 (21 vs 17%) and 80 km/h (20 vs 11%), car crashes on roads with speed limits of 100 km/h or higher (28 vs 19%)
Light conditions	$\chi^2_{(1)}$=52.5, p<.001*	Motorcycle crashes more common during daylight (80 vs 65%)
Weather conditions	$\chi^2_{(1)}$=13.1, p<.001*	Motorcycle crashes more common in dry weather (95 vs 90%)
Road conditions	$\chi^2_{(1)}$=16.9, p<.001*	Motorcycle crashes more common on dry roads (93 vs 87%)

* p<.05.

Table 3. Length of hospitalisation in days for motorcyclists and drivers of cars or SUVs, January 2008 to November 2010 and April 2014 to December 2016

Number of days	Number of riders	% of included	Number of drivers	% of included
< 1	130	17.3	548	34.8
1-5	301	40.1	554	35.2
6-10	127	16.9	187	11.9
11-15	80	10.7	96	6.1
16-20	33	4.4	58	3.7
21-25	29	3.9	42	2.7
26-30	16	2.1	20	1.3
31-35	4	0.5	23	1.5
36 +	31	4.1	47	3.0
Total included cases	751	100.0	1575	100.0
Excluded cases[a]	12		42	
Total of all cases	763		1617	

[a] Cases in which the motorcyclist or driver died after a period of hospitalisation were excluded

= 11.8 (*SD*=8.2), hit obstacle/animal/pedestrian on road = 10.4 (*SD*=8.4), head on = 11.7 (*SD*=6.9), and hit fixed object/parked vehicle = 10.8 (*SD*=9.1). There were different numbers of cases for each of the crash types and some had small numbers (e.g. 14 for left road – out of control) which made examinations of statistical significance difficult. Therefore, these results should be viewed as indicative only that injury severity may be highest for left road – out of control and head on crashes.

Table 4 shows MAIS for each of the six AIS body regions for motorcyclists and drivers. Again, only data from the 2014 to 2016 period were used. The body regions featuring most prominently for motorcyclists were the extremities (243 cases), external regions (241 cases), the chest (116 cases) and the head/neck (100 cases). Facial injuries were the least common. The areas with the most injuries with a MAIS value of 4 or more were the chest (17 cases) and the abdomen (9 cases). In comparison, external regions (429 cases) featured most commonly for car drivers, followed by the head/neck (253 cases), the chest (244 cases) and the extremities (205 cases.) As with motorcyclists, facial injuries were the least common. The areas with the most injuries with a MAIS value of 4 or more were the chest (18 cases) and the head/neck (17 cases). Ninety-six motorcyclists (25.5% of cases with AIS recorded) had injury to one body

Table 4. MAIS for each body region for injured motorcyclists and car drivers, April 2014 to December 2016

MAIS	Abdomen	Chest	External	Extremities	Face	Head/Neck
Motorcyclists						
1	4	2	234	17	16	3
2	38	37	7	175	16	71
3	7	60	0	48	1	23
4	6	12	0	3	0	2
5	3	5	0	0	0	1
Total	58	116	241	243	33	100
Car drivers						
1	5	23	417	12	40	58
2	71	98	11	148	23	132
3	16	105	0	42	1	46
4	4	12	1	3	0	7
5	1	6	0	0	0	10
Total	97	244	429	205	64	253

Table 5. Results of linear regression to predict injury severity (ISS) for motorcyclists, January 2008 to November 2010 and April 2014 to December 2016

Independent variables	B[a]	Beta[b]	*t*	*p*-Value
Age	.09	.15	3.03	*.003
Gender	2.34	.07	1.43	.155
BAC level	1.29	.22	4.32	*<.001
Drug test result	.14	.01	.14	.889
Road surface	.14	<.01	.05	.957
Type of crash	.82	.05	.96	.336
Speed limit	.64	.15	2.82	*.005

[a] The results for B are unstandardised coefficients.
[b] The results for Beta are standardised coefficients.
* p<.05.

region and 281 (74.5% of cases with AIS recorded) had injuries to two or more regions. In comparison, 272 (39.9% of cases with AIS recorded) car drivers had injury to one body region and 410 (60.1% of cases with AIS recorded) had injuries to multiple regions. The difference was statistically significant ($\chi^2_{(1)}$=22.3, p<.001), indicating that motorcyclists more commonly have injuries to multiple body regions.

Finally, linear regression was used to examine the effects of several variables on injury severity for motorcyclists from both periods. The dependent variable was ISS and the independent variables were: age, gender (male or female), BAC level (zero, less than 0.050, 0.050-0.079, 0.080-0.099, 0.100-0.149, 0.150-0.199 and 0.200-0.249), drug test result (positive or negative), road surface (sealed or unsealed), type of crash (single or multiple vehicle) and speed limit (40, 50, 60, 70, 80, 90, 100 and 110 km/h). The 'Enter' method was used to enter all independent variables in the model simultaneously. The model was statistically significant, ($F(7, 372)$=6.1, p<.001), with the independent variables accounting for 8.7% of the variance in ISS (adjusted R^2). Table 5 shows that injury severity was higher for older motorcyclists, motorcyclists with higher BAC, and crashes in areas with higher speed limits.

Discussion

This study examined motorcycle (and scooter) crashes in which the rider was injured and admitted to hospital, in terms of rider characteristics, crash characteristics, injury patterns and injury severity. The findings are summarised and discussed in the following sections.

Sample Characteristics

Crash-involved motorcyclists were younger, more commonly male, more likely to hold a learner permit, less likely to hold a provisional licence, less likely to be over the legal BAC limit and less likely to be at-fault in multiple vehicle crashes than a comparison sample of crash-involved drivers. Only 12 motorcyclists were not wearing a helmet (1.5% of known), which is reflective of compulsory helmet laws in Australia. Patterns and severity of injury to unhelmeted riders could not be examined due to the small number; however, the relationship between non-use of helmets and increased risk of head injury (Rutledge & Stutts, 1993) and increased overall injury severity has been demonstrated in other studies (Brown, Hejl, Bui, Tips, & Coopwood, 2011; Nakahara, Chadbunchachai, Ichikawa, Tipsuntornsak, & Wakai, 2005; Rowland et al., 1996).

Crash-involved motorcyclists were younger and more commonly held a learner permit, consistent with learner riders being permitted to ride on the road unsupervised in South Australia. Crash risk during this period of learning would be high. Indeed, it has been shown that novice motorcyclists have a higher risk of crashes per unit of exposure than more experienced riders (Andrea, 2006). In comparison, learner car drivers are required to be supervised. It is noteworthy then that crash-involved car drivers in the present study more commonly held a provisional licence, which is when they are first allowed to drive unsupervised. Research by Austroads (2008) has shown that car drivers with a provisional licence have a much higher crash risk than car drivers with a learner permit.

The finding that crash-involved motorcyclists were more commonly male is likely to be due, at least in part, to motorcycle riding being more popular amongst males (Auster, 2001). However, Moskal, Martin, and Laumon (2012) found that being a male motorcyclist was a factor that increased the risk of a crash. This suggests that there may more to the over-representation of male motorcyclists in crashes than just their greater number. Across many areas of life (e.g. gambling, financial, health/safety, and recreation), men engage in more risk-taking behaviours than women (Byrnes, Miller, & Scafer, 1999; Harris, Jenkins, & Glaser, 2006; Waldron, McCloskey, & Earle, 2005; Weber, Blais, & Betz, 2002). This is due, in part, to differences in their assessments of risk. Men perceive less risk in risky activities (Weber et al., 2002), while women have a higher perceived likelihood of negative outcomes, higher perceived severity of potential negative outcomes, and lower expectation of enjoyment from risky activities (Harris et al., 2006). Therefore, it is possible that males ride motorcycles in more of a risk-taking manner leading to an overrepresentation in motorcycle crashes. Further research would be needed to determine whether this is true.

The present findings contrast those of Lin and Kraus (2009), Villaveces et al. (2003) and Soderstrom et al. (1995) that motorcycle riders are more likely to have consumed alcohol prior to a crash than car drivers. Lin and Kraus (2009) noted that motorcycle riders are more vulnerable to the effects of alcohol on balance, motor coordination, and judgement. It is possible that most motorcyclists recognise this and avoid drinking and riding, which would explain the finding that crash-involved motorcyclists were less likely to have a BAC over the legal limit than car drivers. The lower likelihood of being over the legal BAC limit may have contributed to the finding that motorcyclists were less likely to be found at-fault in multiple vehicle crashes. The lower likelihood of being at-fault would also be due to the common errors of car drivers in multiple vehicle angle crashes involving motorcyclists at intersections – so-called looked-but-failed-to-see/inattentional blindness errors (Clabaux et al., 2012; Clarke, Ward, Bartle, & Truman, 2007; Crundall, Crundall, Clarke, & Shahar, 2012; Pai, 2009; Pammer, Sabadas, & Lentern, 2018).

Crash Characteristics

The crashes of motorcyclists were more likely to be single vehicle crashes (specifically roll over, left road – out of control and hit object/animal/pedestrian on road crashes) and were more common on weekends, during the afternoon, on sloping roads, on curved roads, on roads with speed limits of 50 and 80 km/h, during daylight hours, in dry weather and on dry roads compared to the crashes of car drivers.

Research by Wells et al. (2004) in Auckland, New Zealand also found that crash related injuries to motorcyclists occurred mainly in areas with a 50 km/h speed limit, during the day, and in fine weather. Motorcyclists would be more likely to be injured in crashes at lower speeds because they are less protected than car drivers. There is also more of a culture of riding motorcycles for leisure rather than practical transport (Jamson & Chorlton, 2009). This would explain why the crashes of motorcyclists were more common on weekends, during the afternoon, during daylight hours, in dry weather and on dry roads because they can choose suitable times and optimal conditions. Wells et al. (2004) also found that motorcyclists were mainly injured in urban zones, which differs from the present finding that the crashes of motorcyclists and car drivers were both evenly split between metropolitan and rural areas. The different results could be due to different geographical study locations.

The finding that motorcyclists were more likely to have single vehicle crashes suggests that they have more crashes precipitated by loss of control. Indeed, examination of the 2014 to 2016 data, for which greater crash type information was available, found that motorcyclists were overrepresented in left road – out of control, roll over and hit object/animal/pedestrian on road crashes. This would also explain the finding that their crashes were more common on sloping and curved roads, as these roads would be more likely to lead to a single motorcycle losing control. Research in Germany by Fredriksson and Sui (2016) also found that loss of control crashes are the most common motorcycle crash types leading to serious injury.

Injury Patterns and Severity

Motorcyclists had a higher level of injury severity than car drivers, spent longer in hospital, and were more likely to sustain injuries to multiple body regions. The injured regions for motorcyclists from most to least common were the extremities, external regions, the chest, the head/neck, the abdomen and facial regions. This differed slightly from drivers, with the injured regions from most to least common being external regions, the head/neck, the chest, the extremities, the abdomen and facial regions. There was evidence to suggest that injury severity for motorcyclists may be highest for left road – out of control and head on crashes. Finally, linear regression showed that older age, higher BAC and higher speed limit were predictive of higher severity of injury to crash-involved motorcyclists.

These findings are consistent with the findings of Van Eslande and Elvik (2012) that serious injuries occur with greater frequency for motorcyclists. They are also consistent with Lin and Kraus (2009) who found that motorcycle riders often sustain multiple injuries in a crash and the most common site of injury is to the lower extremities. Forman et al. (2012) also found that injuries to lower and upper extremities were most common for motorcyclists. Both the increased injury severity and the most common site of injury being to the extremities would be due to the unprotected nature of motorcycle riding. Extremities would be the first point of impact when a rider falls to the road or makes contact with a roadside barrier.

With regard to the regression findings, the relationship between older age and increased injury severity has been found for motorcyclists in other studies (Savolainen & Mannering, 2007) and would be due to the increased fragility that comes with older age. Older road users have a lower tolerance to physical trauma (Evans, 1988; Li, Braver, & Chen, 2003). The relationship between higher speed limits and increased injury severity would be due to increased travelling speed. Although the relationship between travelling speed and the risk of crashes and injuries has been demonstrated conclusively for cars (Kloeden, McLean, Moore, & Ponte, 1997; Elvik, Christensen, & Amundsen, 2004), similar research has not been conducted for motorcycles. This may be due to the greater difficulty associated with computer reconstruction of motorcycle crashes. However, the fact that motorcyclist speed profiles tend to involve higher speeds than other vehicles (Baldock et al., 2012) emphasises the need for speed enforcement on popular high speed recreational riding routes. Consistent with the present findings, alcohol use has previously been shown to be associated with higher risk of injury and increased injury severity in a crash (Nakahara et al., 2005; Rifaat et al., 2012; Savolainen & Mannering, 2007). This association is likely due to other risk-taking decisions that intoxicated riders may be more likely to make, such as speeding and not wearing a helmet or protective clothing. Finally, type of crash with two categories (single or multiple vehicle) was included in the regression analysis and shown not to have an effect on injury severity. However, it is likely that a more detailed crash type variable (e.g. right angle, rear end, etc.) or impact type variable (front, side, rear) would have an effect. This information was not available for all cases and so was not included as a variable in the regression analysis.

Potential Countermeasures to Improve Motorcycling Safety

Potential countermeasures for motorcycle crashes include an improved Graduated Licensing System (GLS), and improvements in infrastructure, vehicle technology and protective clothing. At the time of writing, most jurisdictions in Australia, including South Australia, are considering strengthening their existing motorcycle GLS. Injured motorcyclists were more likely to hold a learner permit than injured car drivers in the present study, which suggests an enhanced GLS (e.g. inclusion of on-road test of abilities for novice riders before they are allowed on the road, requirement that novice riders wear high visibility clothing) is warranted.

One GLS element recommended by Baldock (2018) is the requirement for novice riders to have a zero BAC. Currently, South Australia (along with Western Australia and the Northern Territory) does not require a zero BAC for novice riders, but does require it for novice drivers. Motorcyclists were less likely to have an illegal BAC than car drivers in the present study but the opposite has been found in other studies (Lin & Kraus, 2009; Villaveces et al., 2003; Soderstrom et al., 1995). Also, Moskal et al. (2012) demonstrated that alcohol is the largest risk factor for the crash involvement of motorcyclists. Alcohol consumption is known to affect the necessary skills for safe riding (balance, coordination and judgement) (Lin & Kraus, 2009) and the present study demonstrated that a higher BAC increased injury severity. Therefore, it is reasonable to recommend that a zero BAC for novice motorcyclists would be a beneficial way of strengthening the GLS in South Australia.

A report by Austroads (2016) recommended several road infrastructure-based crash prevention measures for motorcyclists. To reduce single vehicle/loss of control crashes, they recommended: improvements to the road surface (e.g. resurfacing) on curves, curve approaches and departures; improving and maintaining delineation and curve warning signage; lane widening and sealed shoulder widening on curves; and wide centre lines. To reduce multiple vehicle crashes at intersections, they recommended: providing sightlines at intersections to improve sight distances (or intersection warning signs or pavement markings if safe sight distances cannot be provided), separating movements at signalised intersections with designated right turn lanes, and protecting turning motorcycles with channelised right and auxiliary left turn lanes.

Advances in motorcycle technology are also likely to bring safety benefits. Ponte, Searson, Royals, and Anderson (2015) identified combined braking systems, traction control systems and anti-lock braking systems (ABS) as likely to be beneficial and claimed that if all motorcycles sold in South Australia in 2025 were fitted with ABS, the reduction in motorcycle crashes would be around 10 to 25%. Finally, encouraging the uptake of protective clothing is an important measure to reduce injury severity among crash-involved motorcyclists. In particular, an independent rating system could assist motorcyclists to make informed choices about which clothing provides superior protection (de Rome, Gibson, et al., 2012).

Study Limitations

The data only included crashes in which at least one participant had been admitted to hospital. The reason for this was that one of the central purposes of this study was to examine injury patterns and severity and the depth of detail required could only be obtained from detailed hospital admission records. However, a future study could include property-damage only and minor injury crashes (private doctor or hospital treated), as well as crashes in which the rider died at the scene.

Information on the clothing worn by crash-involved motorcyclists (i.e. protective or not) was not routinely collected by either the hospital or police. Consequently, this was not examined. Failure to wear protective clothing is an important factor in the risk and severity of injury to motorcyclists (de Rome et al., 2011) and would ideally be investigated in future research, particularly as a mitigating variable in a regression model to predict injury severity. Other factors that would be interesting to examine in relation to injury severity would be the engine size and type of bike (e.g. sports bike, dirt bike, road bike, cruiser) of crash-involved motorcycles, as well as vehicle age and safety technologies of both motorcycles and cars. Research by Brown et al. (2016) indicated that riders using sports motorcycles have greater odds of being involved in serious injury crashes than riders using other motorcycle types. Vehicle age and safety technologies may also influence the types of crashes that riders and drivers have. However, information on these factors was also not collected in the hospital or police data.

Conclusions

A key strength of this study was that detailed data from hospital records (e.g. injury severity for specific body regions) were linked to police-reported crash data and forensic blood tests for a large sample of injured riders of motorcycles and scooters. Wilson, Begg, and Samaranayaka (2012) have noted the lack of such published linkage studies for motorcycle crashes. These data provided a detailed picture of current crash and injury patterns for a high-risk road user group. A clear understanding of the current situation for motorcycle and scooter riders is necessary in order to facilitate future improvements in their safety.

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Notes

[1] A provisional licence is granted to an individual once they have fulfilled the requirements to progress from a learner permit. A probationary licence is granted after a period of licence suspension (or, in some cases, instead of licence suspension).

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The association of select medical conditions with road transport and other hospitalised injury among older adults

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Key findings

- Older drivers with diabetes, visual disorders or cardio disease had higher odds of injury hospitalisation versus other injuries.
- Medical conditions may affect the ability of older road users to drive or safely cross the road.
- There is a need to identify the impact of multiple medical conditions on road crash risk.

Abstract

Introduction: Certain cognitive and physical conditions have been associated with increased risk of injury, particularly risk of vehicle crashes among older car drivers. This study aims to examine the association of seven select medical conditions among hospitalised road users compared to other hospitalised injuries, and to estimate the hospitalised injury rates of car drivers, car passengers and pedestrians with these medical conditions. **Method**: An examination of road transport and non-road transport hospitalised injury involving adults aged ≥50 years identified during 2003-2012 in New South Wales, Australia was conducted. Medical conditions were identified from hospital diagnosis records. Conditional fixed effects logistic regression conditioned on the matched cases and comparison-cohort estimated odds ratios for each medical condition by road user type. **Results**: There were 35,134 road transport injuries (10,664 car drivers and 4,907 pedestrians) and 447,858 non-road transport injuries. Individuals with vision disorders, cardiovascular disease including stroke, diabetes, and osteoarthritis had higher odds of hospitalisation for an injury as a car driver compared to all other hospitalised injuries. Individuals with diagnoses of dementia or alcohol dependence had a lower odds of an injury hospital admission as a road user (excluding pedestrians) compared to all other hospitalised injuries. **Conclusions**: As the population ages, there are likely to be more older road users with comorbidities that may affect their ability to drive or safely cross the road. Community mobility strategies need to take into account the influence of comorbid health conditions for older adults.

Keywords

older driver, pedestrian, injury, medical conditions

Introduction

Injury in older adults represents a growing burden for public health (Australian Institute of Health and Welfare, 2018b; World Health Organization, 2015). Globally, road crashes are estimated to account for 1.3 million deaths annually and are projected to become the third leading cause of the burden of injury and disease by 2030 (World Health Organization, 2015). In Australia, road trauma results in over 36,000 hospital admissions each year (Australian Institute of Health and Welfare, 2018a), of which an estimated 10% are of people aged ≥65 years (Australian Institute of Health and Welfare, 2018b). Increasing longevity in high income countries (Australian Bureau of Statistics, 2011; United Nations, 2013) means that there will likely be an increase in the number of older drivers as the 'baby boomers' strive to remain independently mobile (Fildes, 2008). Some studies have reported that older drivers have higher crash rates on a per licence or travel distance basis than younger drivers (Charlton et al., 2006; Cheung & McCartt, 2011; Lyman, Ferguson, Braver, & Williams, 2002), and are also more likely to be killed or seriously injured in a crash, largely due to reduced physiological capacity to recover from the trauma (Papa et al., 2014).

As people age, their risk of developing age-associated medical conditions increases. Several medical conditions have been associated with a higher relative risk of a vehicle crash for older drivers (Charlton et al., 2004; Charlton et al., 2010; Dobbs, 2005; Marshall, 2008; National Highway Traffic Safety Authority, 2009; Vaa, 2003) and people with cognitive impairment have been shown to have a higher risk of pedestrian-related trauma (Gorrie, Brown, & Waite, 2008). Certain physical conditions, such as cardiovascular disease or diabetes, can potentially lead to incapacitation while driving, e.g. if an individual experiences cardiac arrhythmia or hypoglycaemia (Charlton et al., 2004; Marshall, 2008; Vaa, 2003). Common age-related vision problems, such as cataracts and macular degeneration, can compromise visual acuity and depth perception (Charlton et al., 2004; Marshall, 2008; Vaa, 2003). Several neurological conditions, such as dementia or Parkinson's disease, can influence an individual's judgement, reaction time and decision making ability (Charlton et al., 2004; Charlton et al., 2010; Marshall, 2008). Conditions, such as alcohol dependence or sleep apnoea, can impair an individual's driving ability and increase the risk of a crash (Charlton et al., 2004; Charlton et al., 2010; Marshall, 2008).

There has been limited examination of medical conditions associated with road transport injury for older adults on a population-wide basis (Charlton et al., 2004). Routinely available administrative data collections, such as hospital records, can allow associations between existing medical conditions and hospitalised injury following a vehicle crash to be examined, which could assist in informing community mobility strategies. In Denmark, road traffic crash risk was examined for older people living with dementia compared to people with no dementia using population registries and identified a lower crash risk for people with dementia (Petersen et al., 2018). Further research is needed to examine associations of a range of medical conditions and road transport hospitalised injury. This research aims to examine the association of seven select medical conditions among older hospitalised road users compared to other hospitalised injuries; and estimate the hospitalised injury incidence rates of car occupants and pedestrians with these select medical conditions in New South Wales (NSW), Australia during 2003 to 2012.

Method

A retrospective population-based nested case-comparison study was conducted of road transport and non-road transport injuries of adults aged ≥50 years identified in linked hospitalisation and mortality records during 1 January 2003 to 31 December 2012. Ethical approval was obtained from the NSW Population and Health Services Research Ethics Committee (2013/09/480). Adults aged ≥50 years represent approximately one-third of the NSW population in 2012 (Australian Bureau of Statistics, 2014).

Data sources and data linkage

NSW hospitalisation data include information on all inpatient admissions from all public and private hospitals. The data contain information on patient demographics (e.g. age, sex), source of referral, diagnoses, external cause(s) and hospital separation type. Diagnoses and external cause codes are classified using the International Classification of Diseases, 10th Revision, Australian Modification (ICD-10-AM) (National Centre for Classification in Health, 2006). Injury hospital admissions were identified using a principal diagnosis classification of ICD-10-AM: S00-T75 or T79. Road transport (i.e. pedestrians: V00-V09; pedal cyclists: V10-V19; motorcyclists: V20-V29; cars: V40-V59; heavy vehicles: V60-V69; buses: V70-V79; and other land transport: V30-V39 and V80-V89) and non-road transport (V90-Y98) hospitalisations were identified using ICD-10-AM external cause classifications. Cars included car derivatives, such as 4-wheel drives, panel and passenger vans, utility vehicles and station wagons. Car occupants included either drivers (ICD-10-AM: fourth character 0 or 5) or passengers (ICD-10-AM: fourth character 1 or 6).

Mortality data were obtained from the NSW Registry of Births, Deaths and Marriages and information obtained included demographic data (e.g. age and sex) and fact of death. The hospitalisation and mortality data were probabilistically linked using identifying information (such as name, address, sex, date of birth) by the Centre for Health Record Linkage (CHeReL). A person project number (PPN) for each unique person is identified in the linkage process and a successful link was defined if the PPN matched in both data collections. Upper and lower probability cut-offs started at 0.75 and 0.25 for a linkage and were adjusted for each individual linkage to ensure false links were kept to a minimum. Record groups with probabilities in between the cut-offs were subject to clerical review.

Identification of medical conditions

Eleven medical conditions previously associated with an increased risk of a vehicle crash (Vaa (2003), Charlton et al (2004), Dobbs (2005) and Marshall (Charlton et al., 2010; 2008)) were identified using diagnosis classifications recorded in any hospital episode of care in up to 40 diagnosis fields in the year of, and the year prior to, identification of the admission of the index injury hospital admission (i.e. a 12 month look-back period to 1 January 2002). A 12-month look back period was used as NSW hospitalisation records were only available for linkage from 1 July 2001, so the first full calendar year for a look back period was 1 Jan 2002 to 31 Dec 2002. Medical conditions were identified using ICD-10-AM classifications: alcohol misuse and dependence (F10, Y90, Y91, Z50.2, Z71.4, Z72.1), cardiovascular disease (CVD) including stroke (I00-I99), dementia (F00-F03, F05.1, G30, G31), diabetes (E10-E14), epilepsy (G40-G41), osteoarthritis (M15-M19), Parkinson's disease (G20-G22), rheumatoid arthritis (M05-M06), stroke, as a subset of CVD, (I60-I64), schizophrenia: (F20-F29), sleep disorders (G47), and vision disorders (i.e. glaucoma: H40-H42, cataract: H25-H26 and H28 and other retinal disorders (including macular degeneration): H35).

Data management and analysis

All analyses were performed using SAS version 9.4 (SAS Institute, 2014). All hospital episodes of care related to the injury event were linked to form a period of care. The hospitalisation data were stratified for each medical condition (i.e. the hospitalisation data was sub-divided anew for each type of case (e.g. injured road user) and medical condition combination at the time of the injury hospitalisation). All injury hospitalisations with a selected medical condition identified at the time of the hospitalisation were identified as 'cases' and all injured road users and other injured patients without the medical condition formed the 'comparison-cohort' groups (Prentice, 1986). Each road user sub-group of cases (e.g. vehicle drivers, passengers, pedestrians) and their comparison-cohort (i.e. other injury hospitalisations) were randomly matched 1:1 on age group and sex. Matching was conducted based on risk-sets, so any injured individual was eligible to be selected as a comparison, until the individual became a case (for example, an individual could be hospitalised more than once during the 10 year time period. If an individual was hospitalised in 2005 for a fall injury, they could be selected as a comparison. If the same individual was hospitalised in 2010 after being injured as a motor vehicle driver, the individual would be a case). Comparison individuals could also be selected as comparisons for more than one case. Conditional fixed effects logistic regression conditioned on the matched cases and comparison-cohort risk-set groups estimated odds ratios (ORs) for each medical condition by road user type (i.e. dependent variable), adjusted for the presence of comorbidities (Y/N) (i.e. independent variable), excluding the medical condition of interest. Ninety-five percent confidence intervals (95%CI) were calculated. The ORs were only examined where cell sizes for each medical condition were of sufficient size.

Thirty-day mortality was calculated from the date of admission of the index road transport injury hospital admission. Hospital length of stay (LOS) was truncated to three standard deviations in order to exclude extreme outliers (National Health Performance Authority, 2013). Denominator data to estimate crude incidence rates per 10,000 licenced car drivers and to estimate crude incidence rates per 100,000 population aged ≥50 years for pedestrians and car occupants were obtained from annual road crash statistics (Centre for Road Safety Transport for NSW, 2013) and the Australian Bureau of Statistics (Australian Bureau of Statistics, 2016), respectively.

Results

All road transport

There were 35,133 road transport and 447,858 non-road transport-related injury hospital admissions in NSW during the ten year period. Car occupants represented nearly half (48.6%) of the road transport injury admissions, with more female (61.0%) car occupants than male (39.2%). Of the medical conditions identified, CVD (40.7% and 58.0%), diabetes (12.3% and 15.3%) and vision disorders (11.6% and 21.0%) were the most commonly recorded comorbidities of the individual injured during road transport and non-road transport hospitalisations, respectively. Approximately half the individuals injured during road transport and 72.2% of individuals injured during non-road transport had one or more of the medical conditions recorded (Table 1).

Car occupants and pedestrians

Among injury hospitalisations, a higher proportion of car drivers were aged 50 to 69 years compared to car passengers and pedestrians. Males represented a higher proportion of car drivers than females (54.2% versus 45.8%) and females a higher proportion of car passengers (75.5% versus 24.5%). For both car occupants and pedestrians, CVD, diabetes and vision disorders were the most common medical conditions recorded. Pedestrians (9.1% and 4.3%) had a higher proportion of alcohol misuse and dependence and dementia recorded than car drivers (5.0% and 1.5%) and car passengers (2.6% and 3.4%), respectively. Pedestrians and car passengers had a higher proportion of multiple medical conditions recorded than car drivers. Pedestrians (16.3 days) had a longer mean hospital LOS than car drivers (7.4 days) and car passengers (7.5 days). Pedestrians also had a higher rate of mortality within 30 days than car drivers and car passengers (Table 2).

Vision disorders, CVD, osteoarthritis and diabetes all were associated with a higher odds of an injury hospital admission for all road users compared to other hospitalised injuries. A diagnosis of dementia had a lower odds of a road injury hospital admission compared to other hospitalised injuries. Alcohol misuse and dependence had a lower odds of an injury hospital admission for all road users, except for pedestrians compared to other hospitalised injuries (Table 3).

For car drivers, the rates of injury hospitalisations per 10,000 licenced car drivers, and for car drivers, car passengers and pedestrians the rates per 100,000 population, tended to increase with age for each medical condition, except for alcohol misuse and dependence where it decreased (Table 4). The hospitalised incidence rates for each injured person will be influenced by the prevalence of a health condition in the population. For example, if cardio-vascular disease had a high prevalence in a population, then it might be expected that this disease would be common in the target population. Examining the injury hospitalisation rates by the number of medical conditions showed that as the number of comorbidities increased the rates decreased. Individuals with no comorbidities identified had the highest hospitalised injury rates (Table 5).

Discussion

The current study identified that older adults with vision disorders, CVD including stroke, diabetes, and osteoarthritis all had higher odds of an injury hospitalisation as a car driver or passenger compared to all other hospitalised injuries, and that older adults with vision disorders, CVD, diabetes, and osteoarthritis all had a higher odds of an injury hospitalisation as a pedestrian compared to all other hospitalised injuries of older adults. As individuals age, aspects of their physical health typically decline, which can increase the likelihood of being involved in a vehicle crash, with older adults more likely to be seriously injured and hospitalised (Cheung & McCartt, 2011).

Injured individuals with a diagnosis of a vision disorder all had higher odds of an injury hospitalisation as a car driver,

Table 1. Road transport and non-road transport-related hospitalised injury in NSW of individuals aged ≥50 years by gender, linked hospitalisation and mortality records 2003-2012

	Road transport (n=35,131)		Non-road transport (n=447,858)		
	n	**%**	**n**	**%**	**χ^2 (df)**
Age group					
50-59	14,116	40.2	92,384	20.6	12,155.0 (4)*
60-69	8,572	24.4	77,142	17.2	
70-79	6,789	19.3	92,964	20.8	
80-89	4,984	14.2	136,051	30.4	
90+	672	1.9	49,314	11.0	
Gender[1]					
Male	19,913	56.7	180,782	40.4	3570.7 (1)*
Female	15,218	43.3	267,074	59.6	
Identified medical condition[2]					
Alcohol misuse and dependence	2,006	5.7	38,795	8.7	367.1 (1)*
Cardiovascular disease	14,312	40.7	259,740	58.0	3952.5 (1)*
Stroke	719	2.1	23,935	5.3	731.3 (1)*
Dementia	862	2.5	67,488	15.1	4267.4 (1)*
Diabetes	4,312	12.3	68,642	15.3	236.7 (1)*
Osteoarthritis	2,611	7.4	52,709	11.8	604.2 (1)*
Vision disorder	4,074	11.6	94,183	21.0	1788.8 (1)*
Epilepsy	40	0.1	1,197	0.3	30.0 (1)
Parkinson's disease	211	0.6	12,187	2.7	585.7 (1)*
Rheumatoid arthritis	#	#	#	#	-
Schizophrenia	244	0.7	6,985	1.6	165.4 (1)*
Sleep disorders	908	2.6	11,422	2.6	0.15 (1)
Multiple medical conditions[3]					
None	16,678	47.5	124,348	27.8	7664.7 (3)*
One	10,171	30.0	127,690	28.5	
Two	5,541	15.8	110,795	24.7	
Three or more	2,741	7.8	85,023	19.0	
Transport mode					
Pedestrian	4,907	14.0	-	-	
Pedal cyclist	3,589	10.2	-	-	
Motorcyclist	3,938	11.2	-	-	
Car[4]	17,091	48.6	-	-	
Driver	10,664	62.4	-	-	
Passenger	3,984	23.3	-	-	
Other[5]	1,321	7.7	-	-	
Unspecified	1,122	6.6	-	-	
Heavy vehicle	713	2.0	-	-	
Bus	1,367	3.9	-	-	
Other land transport	3,528	10.1	-	-	
Non-transport injury mechanism					
Falls	-	-	316,327	70.6	288414.5 (2)*
Inanimate mechanical forces	-	-	41,248	9.2	
Other and unspecified mechanisms	-	-	90,283	20.2	

[1]Gender for 4 individuals was not specified. [2]Not mutually exclusive. [3] Medical conditions included: alcohol misuse and dependence, cardiovascular disease including stroke, dementia, diabetes, epilepsy, osteoarthritis, Parkinson's, schizophrenia, sleep disorders and vision disorders. [4]Percent for car occupants calculated using total number of cars. [5]Includes person boarding or alighting from vehicle and person outside vehicle. # Refers either to cell sizes less than 5 or used to disguise a cell less than 5. * p<0.0001.

Table 2. Hospitalised injuries of car drivers, car passengers and pedestrians in NSW for individuals aged ≥50 years, linked hospitalisation and mortality records 2003-2012

	Car drivers (n=10,664)		Car passengers (n=3,984)		Pedestrians (n=4,907)	
	n	%	n	%	n	%
Age group						
50-59	4,086	38.3	1,147	28.8	1,226	25.0
60-69	2,709	25.4	1,004	25.2	1,113	22.7
70-79	2,233	20.9	1,034	26.0	1,358	27.7
80-89	1,499	14.1	717	18.0	1,061	21.6
90+	137	1.3	82	2.1	149	3.0
Gender[1]						
Male	5,784	54.2	976	24.5	2,439	49.7
Female	4,879	45.8	3,007	75.5	2,468	50.3
Identified medical condition[2]						
Alcohol misuse and dependence	533	5.0	105	2.6	444	9.1
Cardiovascular disease	4,542	42.6	1,816	45.6	2,337	47.6
Stroke	196	1.8	102	2.6	124	2.5
Dementia	164	1.5	137	3.4	211	4.3
Diabetes	1,518	14.2	579	14.5	684	13.9
Osteoarthritis	742	7.0	312	7.8	353	7.2
Vision disorder	1,294	12.1	580	14.6	796	16.2
Epilepsy	#	#	#	#	6	0.1
Parkinson's disease	48	0.5	42	1.1	36	0.7
Schizophrenia	55	0.5	16	0.4	95	1.9
Sleep disorders	282	2.6	73	1.8	97	2.0
Multiple medical conditions[3]						
None	4,910	46.0	1,731	43.4	1,851	37.7
One	3,174	29.8	1,190	29.9	1,558	31.8
Two	1,759	16.5	705	17.7	1,032	21.0
Three or more	821	7.7	358	9.0	466	9.5
Hospital length of stay (days)						
Mean (sd)	7.4 (14.7)		7.5 (14.2)		16.3 (24.1)	
Death within 30 days	98	0.9	45	1.1	137	2.8

[1]Gender for 1 car driver and 1 car passenger was not specified. [2]Not mutually exclusive. [3] Medical conditions included: alcohol misuse and dependence, cardiovascular disease including stroke, dementia, diabetes, epilepsy, osteoarthritis, Parkinson's, schizophrenia, sleep disorders and vision disorders. # Refers either to cell sizes less than 5 or used to disguise a cell less than 5.

passenger or pedestrian compared to all other hospitalised injuries. Previous studies have identified that visual disorders are associated with a 1.1 to 2.0 increased crash relative risk for drivers (Charlton et al., 2004; Vaa, 2003; Vernon et al., 2002). An estimated 9.4% of adults aged ≥55 years are visually impaired in Australia (Australian Government Department of Health, 2008). Vision problems can occur when static and/or dynamic visual acuity declines leading to problems with focusing on near or moving objects, respectively, or when an individual's ability to respond to glare or to contrasting signals, such as traffic lights is diminished (Morgan & King, 1995; Owsley et al., 1998).

Individuals with a diagnosis of CVD and diabetes all had higher odds of an injury hospitalisation as a car driver, passenger or pedestrian compared to all other hospitalised injuries. Previous studies have identified associations of CVD and increased crash risk (Dobbs, 2005), identifying a 1.1 to 5.0 increased crash relative risk for drivers with CVD (Charlton et al., 2004; Vaa, 2003). Similarly, in a six month study of injured pedestrians aged ≥65 years in Egypt, CVD was among the most common comorbid

Table 3. Odds ratio and 95% confidence intervals of select medical conditions for hospitalised injuries of road transport, car drivers, car passengers and pedestrians compared to other hospitalised injuries using age and gender matched cohort-controls in NSW for individuals aged ≥50 years, linked hospitalisation and mortality records 2003-2012

Medical conditions[1]	All road transport		Car drivers		Car passengers		Pedestrians	
	OR[2]	95%CI	OR[2]	95%CI	OR[2]	95%CI	OR[2]	95%CI
Alcohol misuse and dependence	0.58*	0.53-0.63	0.43*	0.43-0.57	0.41*	0.31-0.53	1.04	0.88-1.24
Cardiovascular disease	1.80*	1.72-1.87	1.88*	1.75-2.01	1.81*	1.63-2.01	1.85*	1.70-2.03
Stroke	1.47*	1.26-1.72	1.46*	1.13-1.90	1.71*	1.20-2.48	1.41**	1.05-1.92
Dementia	0.20*	0.18-0.22	0.13*	0.11-0.16	0.22*	0.18-0.27	0.24*	0.20-0.28
Diabetes	1.14*	1.07-1.20	1.37*	1.25-1.50	1.35*	1.18-1.56	1.09*	0.96-1.23
Osteoarthritis	2.17*	1.97-2.39	2.17*	1.85-2.54	1.83*	1.48-2.27	1.76*	1.45-2.15
Vision disorder	7.09*	6.29-8.02	8.62*	7.02-10.69	6.98*	5.31-9.33	7.37*	5.83-9.43

[1]Not mutually exclusive and for each medical condition the referent group is the absence of the same medical condition.
[2]Adjusted for the presence of comorbidities, excluding the medical condition of interest. *$p<0.0001$; **$p=0.02$.

conditions identified (Sklar, Demarest, & McFeeley, 1989). In Australia, it is estimated that 62% of individuals aged ≥75 have CVD (Australian Institute of Health and Welfare, 2011), while diabetes affects approximately 990,000 Australians (Australian Institute of Health and Welfare, 2013) and it is estimated that individuals aged ≥55 years make up 50% of all type 1 diabetes and 77% of all type 2 diabetes cases (Australian Institute of Health and Welfare, 2013). If an individual experiences dramatic fluctuations in blood sugar, this could affect their driving ability as fluctuating blood sugar levels are associated with impaired cognition and psychomotor skills (Hakamies-Blomqvist, Siren, & Davidse, 2004; Lonnen, Powell, Taylor, Shore, & MacLeod, 2008; Marshall, 2008). It has been speculated that changes in treatment, improved medications, better monitoring of blood glucose levels, and better overall management of diabetes is likely to reduce the risk of drivers with diabetes having a road crash (Charlton et al., 2010).

Injured individuals with a diagnosis of osteoarthritis all had 2.2 times the odds of an injury hospitalisation as a car driver compared to all other hospitalised injuries. Previously, associations between arthritis and associated musculoskeletal disorders have been associated with a 1.1 to 2.0 increased crash relative risk for drivers (Charlton et al., 2004; Vaa, 2003). Musculoskeletal disorders, particularly, osteoarthritis, are relatively common among older individuals and can impair physical mobility by affecting a driver's ability to grip and turn the steering wheel and to accelerate and brake (Marshall, 2008; Morgan & King, 1995).

The current study found individuals with a diagnosis of alcohol misuse and dependence or dementia had a lower odds of an injury hospitalisation for all road users (excluding pedestrians) compared to all other hospitalised injuries. Previously, associations between alcohol misuse and dependence or dementia have been associated with an increased crash risk (Charlton et al., 2010; Dobbs, 2005), with a 2.0 to 5.0 increased crash relative risk for drivers with known alcohol dependence (Charlton et al., 2004; Charlton et al., 2010; Vaa, 2003) and a 1.5 to 5.0 increased crash risk for drivers with dementia (Charlton et al., 2004; Charlton et al., 2010; Vaa, 2003) identified. In contrast, a 57% lower odds of a road traffic crash was found in Denmark for older adults with dementia (Petersen et al., 2018). Over an extended period of time, alcohol dependence can reduce reaction time and impair cognition and judgement, which can lead to an increased crash risk (Marshall, 2008). Likewise, dementia can affect an individual's driving ability as it can involve memory loss, reduction in attention span, longer reaction times and impaired judgement (Adler & Silverstein, 2008; Dubinsky, Stein, & Lyons, 2000; Marshall, 2008; Morgan & King, 1995). The results of the current study suggests that these medical conditions are either not being reported in hospital diagnosis classifications and/or they increase the injury risk equally for both road users and other hospitalised injuries and/or that drivers and pedestrians with these medical conditions may cease driving, limiting the conditions under which they drive, or may seek assistance when travelling as a pedestrian, respectively.

Self-regulation

Some older adults may self-regulate their driving to take into account their changing driving capabilities (Charlton et al., 2006; Molnar et al., 2013) by limiting the time they drive in challenging conditions, such as by limiting the distance they drive, limiting their driving during inclement weather or at night, or by reducing their driving in busy, peak periods (Charlton et al., 2006; Hakamies-Blomqvist et al., 2004; Molnar et al., 2013; Petersen et al., 2018). Some older drivers will only drive in familiar local areas and others

Table 4. Age-specific incidence rates for hospitalised injuries of car drivers, car passengers and pedestrians in NSW aged ≥50 years for a number of medical conditions1, linked hospitalisation and mortality records 2003-2012

Age group	Dementia		Diabetes		Osteoarthritis		Alcohol misuse and dependence		Cardiovascular disease (including stroke)		Stroke		Vision disorders	
	Rate	**95%CI**	rate	95%CI	rate	95%CI	rate	95%CI	rate	95%CI	rate	95%CI	rate	95%CI
Car drivers[2]														
50-59	0.2	0.08-0.29	6.0	5.42-6.60	2.1	1.73-2.43	4.3	3.84-4.85	15.8	14.91-16.81	0.6	0.45-0.83	1.0	0.82-1.32
60-69	0.3	0.19-0.53	8.6	7.84-9.51	3.2	2.68-3.70	2.5	2.10-3.01	22.2	20.92-23.58	0.8	0.55-1.06	3.5	3.04-4.12
70+	3.6	3.02-4.26	18.1	16.74-19.46	11.8	10.69-12.89	3.0	2.50-3.63	62.4	59.96-65.00	3.0	2.52-3.66	27.6	25.94-29.30
Total	1.1	0.90-1.23	9.8	9.30-10.29	4.8	4.45-5.14	3.4	3.15-3.74	29.3	28.44-30.15	1.3	1.09-1.45	8.3	7.90-8.81
Car drivers[3]														
50-59	1.3	0.63-2.26	46.8	42.33-51.53	16.1	13.53-18.98	33.8	30.03-37-87	123.7	116.45-131.35	4.8	3.48-6.52	8.2	6.37-10.29
60-69	2.5	1.45-4.11	67.0	60.80-73.72	24.5	20.80-28.68	19.6	16.30-23.37	172.3	162.23-182.84	6.0	4.25-8.24	27.5	23.57-31.91
70+	20.0	16.82-23.69	100.5	93.10-108.27	65.4	59.45-71.72	16.8	13.89-20.19	347.3	333.50-361.59	17.0	14.02-20.35	153.4	144.27-162.98
Total	7.5	6.39-8.73	69.4	65.91-72.93	33.9	31.50-36.43	24.4	22.33-16.51	207.5	201.52-213.63	9.0	7.74-10.30	59.1	55.94-62.43
Car passengers[3]														
50-59	0.6	0.19-1.34	13.3	11.01-15.98	4.6	3.28-6.26	6.2	4.66-8.09	34.9	31.11-39.08	2.2	1.31-3.41	3.1	2.04-4.51
60-69	1.1	0.44-2.28	21.3	17.89-25.26	11.9	9.33-14.86	3.6	2.30-5.46	64.8	58.69-71.40	2.8	1.69-4.50	8.4	6.28-10.96
70+	18.3	15.22-21.78	48.0	42.92-53.45	28.8	24.93-33.13	4.1	2.72-5.92	161.2	151.79-170.96	9.5	7.34-12.12	73.1	66.85-79.82
Total	6.3	5.25-7.40	26.5	24.34-28.70	14.3	12.72-15.93	4.8	3.92-5.81	83.0	79.19-86.87	4.7	3.80-5.66	26.5	24.39-28.75
Pedestrians[3]														
50-59	1.5	0.80-2.55	11.4	9.24-13.85	4.6	3.28-6.26	25.8	22.58-29.46	36.5	32.63-40.78	1.6	0.88-2.70	2.9	1.86-4.24
60-69	2.7	1.57-4.30	27.0	23.13-31.40	11.1	8.63-13.98	17.4	14.29-20.96	73.7	67.13-80.67	3.2	1.93-4.88	12.3	9.75-15.39
70+	26.5	22.75-30.62	60.5	54.85-66.67	35.5	31.21-40.30	15.9	13.09-19.23	227.1	215.96-238-70	13.2	10.58-16.18	101.3	93.94-109.18
Total	9.6	8.38-11.03	31.2	28.95-33.68	16.1	14.49-17.90	20.3	18.44-22.26	106.8	102.48-111.19	5.7	4.71-6.75	36.4	33.88-38.98

[1]Not mutually exclusive. [2]Incidence rate per 10,000 licenced car drivers. [3]Incidence rate per 100,000 population.

Table 5. Age-specific incidence rates hospitalised injuries of car drivers, car passengers and pedestrians in NSW aged ≥50 years by comorbidity status1, linked hospitalisation and mortality records 2003-2012w

Age group	No comorbidities		1 comorbidity		2 comorbidities		3+ comorbidities	
	Rate	95%CI	rate	95%CI	rate	95%CI	rate	95%CI
Car drivers[2]								
50-59	53.1	51.34-54.82	5.4	4.82-5.93	1.2	1.00-1.55	0.3	0.19-0.47
60-69	44.7	42.86-46.62	7.5	6.79-8.35	1.9	1.53-2.32	1.0	0.76-1.34
70+	72.3	69.65-75.08	19.3	17.93-20.75	6.5	5.76-7.41	3.4	2.81-4.00
Total	55.1	53.98-56.32	9.5	8.99-9.96	2.8	2.50-3.03	1.3	1.11-1.47
Car drivers[3]								
50-59	355.2	342.81-367.97	85.5	79.44-91.81	23.2	20.12-26.64	5.5	4.07-7.31
60-69	291.5	278.34-305.11	91.5	84.22-99.29	36.2	31.66-41.20	9.0	6.82-11.67
70+	282.0	269.51-294.83	184.1	174.09-194.58	80.4	73.85-87.45	19.3	16.15-22.89
Total	313.6	306.22-321.10	118.0	113.46-122.60	44.8	42.06-47.71	10.8	9.49-12.30
Car passengers[3]								
50-59	114.1	107.09-121.40	13.1	10.80-15.73	3.6	2.42-5.06	1.0	0.47-1.96
60-69	131.5	122.73-140.77	18.0	14.86-21.65	5.8	4.12-8.06	3.3	2.05-5.07
70+	188.2	178.07-198.79	53.4	48.04-59.15	17.4	14.42-20.83	9.1	6.95-11.62
Total	142.2	137.22-147.26	27.1	24.96-29.36	8.5	7.36-9.86	4.2	3.39-5.15
Pedestrians[3]								
50-59	120.4	113.22-127.92	16.1	13.53-18.98	3.4	2.33-4.92	0.9	0.40-1.81
60-69	138.8	129.76-148.28	26.1	22.25-30.38	7.0	5.05-9.34	4.1	2.68-6.02
70+	268.1	255.93-280.63	72.4	66.15-79.06	23.8	20.32-27.79	11.3	8.89-14.07
Total	171.7	166.29-177.32	36.5	34.06-39.17	10.8	9.49-12.30	5.1	4.17-6.11

[1] Medical conditions included: alcohol misuse and dependence, cardiovascular disease including stroke, dementia, diabetes, epilepsy, osteoarthritis, Parkinson's, schizophrenia, sleep disorders and vision disorders.
[2]Incidence rate per 10,000 licenced car drivers.
[3]Incidence rate per 100,000 population.

enlist support from passengers to co-pilot when they drive (Carr & Ott, 2010), while others indicate that they avoid busy traffic and intersections without traffic lights (Charlton et al., 2006). However, self-regulation by older drivers relies upon individuals being aware of their declining ability to drive safety (Holland & Rabbitt, 1992; Morgan & King, 1995). This is not to say that all older drivers with a medical condition should cease driving. Some individuals who have early stages of Alzheimer's disease may be competent to drive for several years (Dawson, Anderson, Uc, Dastrup, & Rizzo, 2009).

Importance of mobility and crash avoidance technology

Mobility is important for older adults in order to maintain their independence and freedom, decrease their social isolation, and to maintain quality of life (Fildes, 2008). In the United States, an estimated 600,000 adults aged ≥70 years cease driving each year and become reliant on others to provide transportation assistance (Foley, Heimovitz, Guralnik, & Brock, 2002). Decisions to cease driving can be affected by the availability and cost of alternative transport options as well as by an older adult's willingness to consider such options. In NSW, current licensing requirements specify that drivers aged ≥75 years must have an annual health review by their general practitioner (GP) to assess fitness to drive. Once a driver reaches 85 years, they have the option to accept a restricted licence (e.g. driving only short distances from home or at specific times of day) or undertake a practical driving assessment every two years. In Australia, national guidelines have been developed to assist health professionals with assessing fitness to drive (Austroads, 2017). In addition, suggested management strategies for GPs to assess driving ability for different medical conditions, including dementia have been proposed (Carmody, Traynor, & Iverson, 2012).

It is possible that some currently available in-vehicle technology, such as electronic stability control, lane departure warnings and crash avoidance technology, will aid older drivers to maintain their ability to drive longer (Hakamies-Blomqvist et al., 2004). In addition, a number of suggestions have been made regarding road design improvements to support older drivers, such as lighting and turn arrows at intersections (Hakamies-Blomqvist et al., 2004). Driving re-training assistance might also be relevant for some medical conditions, such as stroke or arthritis (Hakamies-Blomqvist et al., 2004).

Influence of multiple medical conditions

This study identified 24.2% of car drivers and 30.5% of pedestrians had multiple medical conditions and that as the number of comorbidities increased the incidence rates decreased. It is likely that individuals with multiple medical conditions may have had less exposure to driving and walking. The impact of multiple medical conditions on driving performance and pedestrian-vehicle collision risk among older adults is largely unknown (Marshall & Man-Son-Hing, 2011; Papa et al., 2014; Petersen et al., 2018). One study that examined crash-risk of drivers of all ages with multiple medical conditions compared to matched controls identified that drivers with multiple medical conditions had higher rates of at-fault crashes than their controls over a five year period (Vernon et al., 2002).

Limitations

There are limitations associated with the current study. The results represent associations with car driver and pedestrian hospitalised injury only as no 'at-fault' information was available regarding the crash. Only medical conditions that were relevant to the current hospital episode of care are reported in each hospitalisation record, so identification of conditions may be under-enumerated. However, by using a one year look-back period, better estimates of the prevalence of medical conditions were likely to have been obtained. It is possible that combinations of medical conditions could have a worsening effect on driving ability and the effects of multiple comorbidities were not able to be examined for the conditional fixed effects logistic regression analysis. No information was available on medications that an individual was taking at the time of the crash, the medical conditions experienced by individuals who died prior to hospital, medical conditions of the individual not recorded in hospital records, or the severity of an individual's medical condition. No information was available on older individuals with medical conditions who were not involved in a road transport event that required hospitalisation, so no injury incidence rates for the proportion of the population that experience a particular medical condition could be calculated. Also, no information was available on the time spent driving or as a pedestrian for individuals with certain medical conditions that could be used to more accurately estimate driving or pedestrian injury risk. It is certainly possible that individuals with various medical conditions self-regulated their driving exposure and were thus more often a vehicle passenger than a vehicle driver, and were less likely to be driving rather than walking. The same could also be true for a person with osteoarthritis of the lower limbs who might be less likely to be a pedestrian. Data validity was not able to be assessed and it is possible that there could be some misclassification in records. For example, 6.5% of vehicle occupants had an unspecified position in the vehicle and some of these occupants may have been drivers.

Conclusion

Mobility is important for older individuals to maintain their independence. As the population continues to age, there is likely to be a growing number of older drivers and pedestrians with comorbidities that may affect their ability to drive or cross the road safely. This study has shown that older individuals with medical conditions, such as vision disorders, CVD, diabetes and osteoarthritis, all had a higher odds of an injury hospitalisation as a car driver, passenger or pedestrian compared to individuals hospitalised with all other injuries. This has implications for community mobility strategies. Further work needs to be conducted to establish population-based estimates of crash risk, and also of driving exposure. There is also a need to identify the impact of multiple medical conditions on crash risk.

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Evaluation of the performance of Alcohol and Drug Awareness Courses provided in the ACT

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Key Findings

- Performance of Alcohol and Drug Awareness Courses provided in the ACT evaluated;
- Course completion rates increased from 94% in 2012 to 99% in 2017;
- Effect on attendees' knowledge and attitudes towards drink/drug driving unclear;
- Courses have correlated with reductions in drink driving detections in the ACT;
- Based on these findings, the program has been performing well since its inception.

Abstract

Driving while impaired by alcohol or drugs is a significant road safety issue. As of November 2011, drivers in the Australian Capital Territory (ACT) who have been found guilty of a drink or drug driving offence are required to undertake an Alcohol and Drug Awareness Course (ADAC) before being issued with a restricted or probationary licence. This study evaluated the performance of the ADACs. Key performance indicators on their provision (e.g. enrolments) were obtained from the ACT Government for 2012 to 2017. Surveys of knowledge and attitudes towards drink and drug driving were given to 94 attendees immediately before and after ADACs between August and November 2017. Data on drink driving detections in the ACT between 2002 and 2016 were also obtained from the ACT Government. Completion rates for ADAC attendees increased from 94% in 2012 to 98% in 2016 and 99% in the first half of 2017. Results of the surveys suggested that the courses improved attitudes towards drink driving, although this result may be unreliable due to methodological limitations. The limitations of the surveys may also have contributed to the finding that knowledge of drink and drug driving information did not improve. Finally, the introduction of ADACs has correlated with a reduction in drink driving detections in the ACT between 2012 and 2016. However, the reduction is also likely to be at least partially due to other factors (e.g. other drink driving countermeasures). Based on these findings, the ADAC program has been performing well since its inception.

Keywords

Driver impairment, Drink Driving, Drug Driving, Education, Remediation, Evaluation

Introduction

Driving while impaired by alcohol or other drugs is a significant international road safety issue. In Australia, driving while impaired by alcohol is the leading contributing factor in around 30% of fatal crashes (Australian Transport Council, 2011). In the Australian Capital Territory (ACT), impaired driving due to alcohol, drugs, or a combination of both has been implicated in 50% of fatal crashes between 2007 to 2009 (Justice and Community Safety Directorate, 2011).

The most commonly used road safety countermeasure to address drink driving in Australia is random breath testing (RBT). Victoria was the first state in Australia to introduce RBT to detect alcohol in the mid 1970s, with other states commencing RBT in the 1980s (Baldock and Woolley, 2013). Roadside testing of drivers for illicit drugs has been introduced more recently, starting with Victoria in December 2004 (Baldock and Woolley, 2013). However, it was not until May 2011 that roadside testing for drugs commenced in the ACT.

Another common countermeasure that has been introduced in the ACT (in 2014) is the Alcohol Ignition Interlock Program and associated counselling. An alcohol interlock is an electronic breath testing device wired into the ignition of a vehicle which requires the driver to blow an alcohol-free breath sample (0.00 BAC) into the device before the vehicle will start. For the program in the ACT, a person will be subject to a mandatory interlock condition on their probationary driver licence following a period of licence disqualification if they have been convicted or found guilty of a high range (0.15 BAC or higher) drink driving offence, they refuse to provide a breath or blood sample related to alcohol, or at the time of conviction or finding of guilt they have two previous drink driving charges in the past five years. If a person is convicted of a drink driving offence but does not meet the conditions for a mandatory interlock condition, they can apply to have a voluntary interlock condition on a probationary licence immediately after the court imposes a disqualification. Research has shown that alcohol interlocks reduce recidivism amongst offenders while the device is fitted in their vehicle (Beck, Rauch, Baker, and Williams, 1999; Bjerre and Thorsson, 2008; Chamberlain and Solomon, 2012; Elder et al., 2011; Magnusson, Jakobsson, and Hultman, 2011; Raub, Lucke, and Wark, 2003; Sheehan, Schonfeld, Watson, King, Siskind, and Freeman, 2006; Voas, Marques, Tippetts, and Beirness, 1999).

As of the 25th of November 2011, all drivers in the ACT who have been found guilty of a drink or drug driving offence are required to undertake an Alcohol and Drug Awareness Course (ADAC) before being issued with a restricted or probationary licence. The aim of the ADACs is to raise awareness about the effects of alcohol and drugs on driving and health, and to change the behaviour of drink and drug driving offenders by getting them to take responsibility for their problem alcohol and drug use and commit to reducing it. There are two types of ADAC. The standard course (single two-hour session) is an educational awareness course (i.e. enhance participant knowledge) and is mandatory for first time offenders who have been found guilty of drink driving with a blood alcohol concentration (BAC) less than .08 or a positive detection of drugs in oral fluid. The extended course (two three-hour sessions, one week apart) is a therapeutic (i.e. change participant behaviour and attitudes) and educational awareness course and is mandatory for repeat offenders and first-time drink driving offenders with a BAC of .08 or higher. Drivers who refuse or fail to provide a required sample (breath, oral fluid, blood) are also required to attend the extended course. Two organisations currently provide ADACs in the ACT: the Road Ready Centre (part of Ascent Training Services) and Karralika Programs Incorporated. While both the Road Ready Centre and Karralika Programs deliver the extended course, the Road Ready Centre is the sole provider of the standard course.

Educational and behavior change programs similar to the ADAC program have been evaluated in other studies and have been shown to have the ability to change the attitudes of attendees. Wilson, Palk, Sheehan, Wishart, and Watson (2017) reported on a pilot of an online self-help interactive educational and behavioural program in Australia called 'Steering Clear'. This was designed to prevent recidivism in first time drink driving offenders. Although the sample was small (N=15), all participants reported their intention to think about changing their alcohol consumption and to refrain from drinking and driving. Dawber and Dawber (2013) found that a therapeutic group intervention that targeted recidivist drink and drug drivers in New Zealand named 'One for the Road' led to positive attitude change. Of 570 individuals who completed the intervention, 80% had increased their motivation to change their behaviour.

Similar programs have also been shown to have a direct effect of reducing the recidivism of attendees. Ma, Byrne, Haya, and Elzohairy (2015) and Wickens, Flam-Zalcman, Mann, Stoduto, Docherty, and Thomas (2016) evaluated the 'Back on Track' program that has been conducted in Canada since 2000 for convicted drink drivers following a period of licence suspension and found it led to a significant reduction in drink driving recidivism. Wells-Parker, Bangert-Drowns, McMillen, and Williams (1995), undertook a meta-analysis of a number of studies evaluating the effect of remedial programs on drink driving recidivism. The found that, on average, remedial programs reduced recidivism by 7 to 9% compared to punitive methods (e.g. licence suspension). They also indicated that programs that combine education, treatment and supervision reduced recidivism by an average of 24%.

The purpose of the present study was to evaluate the capacity of the ADAC program to achieve the desired outcomes. Evaluation is an important process and is integral to the success of behaviour change programs. Evaluation ensures that a program performs as intended and achieves the desired outcomes, and, if necessary, can help achieve these by identifying areas for improvement. The ADAC program was evaluated in terms of: (1) key performance indicators (KPIs) on the provision of the courses (e.g. enrolments, attendance), (2) their efficacy in improving the knowledge and attitudes of attendees, and (3) their effect on drink driving detections in the ACT.

Methods

The methods section is divided into the following three sections according to the three components of the evaluation of the ADACs: the examination of KPIs, the survey of attendees immediately before and after ADACs regarding knowledge and attitudes towards drink and drug driving, and the examination of data on drink driving detections in the ACT. Ethical approval from a Human Research Ethics Committee was not required for this evaluation as the project met with the criteria outlined in the document *Ethical Considerations in Quality Assurance and Evaluation Activities* from the National Health and Medical Research Council of the Australian Government (available at https://www.nhmrc.gov.au/about-us/resources/ethical-considerations-quality-assurance-and-evaluation-activities).

Key Performance Indicators

KPIs for ADACs are collected monthly by the course providers, the Road Ready Centre and Karralika Programs, and are supplied to the Justice and Community Safety Directorate in the ACT. Data were obtained for the present evaluation from the Justice and Community Safety Directorate for December 2011 (when the ADAC program began) to August 2017 (most recent data available). The data were examined by calendar year for both courses (standard and extended) and both providers combined, and included: number of courses delivered, number of participants enrolled, number of participants in attendance, average number of participants per course (participants in attendance divided by courses delivered), number of participants completing the course, and percent of participants in attendance who completed the course.

Survey of Course Attendees

Pre- and post-course surveys were undertaken with ADAC attendees. These surveys measured the baseline (pre-course) and immediate post-course knowledge and attitudes towards drink and drug driving.

Participants

Participants were attendees of ADACs between August and November 2017. The total sample was 94 (21 females, 73 males), with 43 from the standard course and 51 from the extended course. The age of participants ranged from 18 to 71 years, with a mean of 31.8 years (*SD*=11.2).

Materials

Both surveys (pre- and post-course) were identical, they contained the same items and were divided into the same two sections – knowledge and attitudes. Participants firstly had to report their age and gender, then the knowledge section contained 9 questions about their understanding of BAC limits, detectable drugs, the time that alcohol/drugs stay in a person's system, effects of drink/drug driving on crash risk, penalties for repeat drink driving offences and myths related to sobering up after drinking or taking drugs. Next, the attitudes to drink driving section required participants to agree or disagree with 14 statements reflecting attitudes towards the danger of drink driving, the effect of drinking on driving ability, general acceptability of drink driving and the current blood alcohol concentration limit of 0.05. Three statements were favourable to safe driving attitudes (i.e. oppose drink driving), such as 'there are no excuses for drink driving', for which an agreed response was ideal. Eleven statements were unfavourable to safe driving attitudes (i.e. support drink driving), such as 'it's ok to drive after a few drinks', for which a disagreed response was ideal. The knowledge questions and attitudes statements were devised by the authors to reflect the content of the ADACs and are provided in full in Appendix A (correct/ideal responses highlighted).

Procedure

ADAC attendees were given an information sheet and the pre-course survey when they first arrived at the course. The information sheet described the purpose of the research, explained that participation required completion of two brief surveys and assured participants that the information they provided would be kept confidential and that their participation was voluntary. They completed the post-course survey immediately after the conclusion of the course (at the end of the single session for the standard course, or the end of the second session a week later for the extended course). Completion of the surveys was taken as agreement to participate in the evaluation. Surveys were completed by every attendee of the courses in which they were distributed (100% response rate).

The intention of the analysis of the survey data was to determine whether the participants' responses to the questions significantly improved immediately after they had attended the course compared to before. To do this, the percentages of correct responses to the knowledge questions and agreed responses to the favourable statements and disagreed responses to unfavourable statements (of participants who provided valid responses, which was not always the full 94 individuals) in the pre-course surveys were compared to the percentages in the post-course surveys. Ninety-five percent confidence intervals were calculated for these percentages for the pre- and post-course surveys and differences were deemed statistically significant if there was no overlap. The percentage increase or decrease in correct and agreed/disagreed responses between the surveys was also examined. Multiple correct responses were possible for several knowledge questions, however, which meant the participant would receive a score (e.g. out of 5). For these questions, means, standard deviations and paired-samples *t*-tests were used to examine differences between responses in the surveys. An alpha level of 0.05 was used to determine statistical significance.

Data on Drink Driving Detections in the ACT.

The following data were obtained from the Performance Statistics section of ACT Policing and the ACT Government's Criminal Justice Statistical Profiles (available online at http://www.justice.act.gov.au/criminal_and_civil_justice/criminal_justice_statistical_profiles):

- the number of random breath tests (RBT) conducted (calendar years 2002-2016),
- the number of persons charged with drink driving (calendar years 2002-2016),
- and the number of first time drink driving offenders, the number of repeat offenders and the number who refused to provide a sample (financial years 2001/02-2015/16).

Procedure

In order to examine whether the introduction of the ADACs in November 2011 had an effect on drink driving detections, the number of persons charged with drink driving in the ACT between the calendar years of 2002-2016 was examined. The average change (increase or decrease) per year between 2002 and 2011 (years of available data before ADACs were introduced) was calculated and then applied to the years 2012 to 2016. This provided a projected model of detections for 2012 to 2016 if the trend between 2002 and 2011 had continued (and hypothetically if ADACs had not been introduced) and was compared to the actual number of detections between 2012 and 2016. The rate of detections per 1,000 RBTs (calendar years 2002-2016) was also examined, along with a projected trend for 2012 to 2016 using the same process described above (i.e. based on 2002 to 2011 trend). This was done because changes in the number of RBTs in the ACT between 2002 and 2016 could account for any changes in the number of drink driving detections over the same period. Additionally, the rate of detections per 1,000 RBTs was considered to be the best proxy measure for drink driving in general as it is a reflection of the proportion of offenders in the general driving population. It should be noted, however, that examining trends in drink driving detections is an indirect way to examine the extent of overall drink driving and it also cannot demonstrate a direct causal effect between ADACs and the number of drink driving detections. Finally, types of offences (first, repeat, refused to provide a sample) were examined as proportions of total drink driving detections by financial year (2001/02-2015/16), and projected trends for total repeat offences for 2011/12 to 2015/6 were calculated (based on 2001/02 to 2010/11 trends). Roadside drug testing (RDT) was introduced in the ACT (May 2011) around the same time the ADAC program commenced (November 2011). As such, there were no historical data on RDTs before the introduction of ADACs on which to base trends and predictions. Therefore, it was not possible to examine the effect ADACs have had on drug driving detections in the ACT.

Results

The results section is, again, divided into the following three sections: the examination of KPIs, the examination of the survey data and the examination of the drink driving detection data.

Examination of Key Performance Indicators

Table 1 shows increases between 2012 and 2014 in: courses delivered (11.7%), participants enrolled (67.3%), attendance (73.8%), participants per course (56.7%), and participants completed (51.5%). Despite declines between 2015 and 2016, these performance indicators remained higher in 2016 than in 2012. Of particular note, the percentage of attendees completed increased from 94% in 2012 to 98% in 2016 and 99% in the first half of 2017 (overall increase of 5.4%).

Effect of the Courses on the Knowledge and Attitudes of Attendees

Percentages of participants who correctly answered the knowledge questions requiring a single response in the pre and post surveys are compared in Table 2 (see Appendix A for questions in full, with correct answers highlighted). For all results, there were overlap in the 95% confidence intervals for the pre and post survey percentages indicating that none of the differences were statistically significant.

Table 1. KPIs for the ADAC courses (calendar years 2012 to 2017)

	2012[a]	2013	2014	2015	2016	2017[b]	Total
Courses delivered	94	107	105	101	99	51	557
Participants enrolled	710	1001	1188	1189	1138	532	5758
Participants in attendance	634	934	1102	1093	988	445	5196
Students per course (in attendance/courses delivered)	6.7	8.7	10.5	10.8	10.0	9.0	9.3
Participants completed course	596	901	1082	1073	970	441	5063
% completed (of total attendance)	94.0	96.5	98.2	98.2	98.2	99.1	97.4

[a] Includes December 2011, when ADAC commenced
[b] Only includes January to June 2017

Table 2. Results of pre- and post-course knowledge questions (N=94)

Question	Pre survey % correct (95%CI)	Post survey % correct (95%CI)	% improvement
BAC limit for a fully licensed driver?	90.0% (83.8-96.2)	97.8% (94.8-100.0)	8.7%
How long for the body to remove one standard drink?	64.0% (53.9-74.1)	66.7% (56.4-77.0)	4.2%
Methylamphetamine can be detected for at least 24 hours?	91.1% (85.2-97.0)	98.9% (96.7-100.0)	8.6%
Increase of crash risk at BAC of .05	60.4% (50.4-70.5)	65.1% (55.0-75.2)	7.8%
Coffee/energy drinks good way to sober up before driving?	92.4% (87.0-97.8)	96.6% (92.8-100.0)	4.5%
Can still be over the limit when you wake up after drinking?	100.0% (100.0-100.0)	98.9% (96.7-100.0)	-1.1%

Table 3. Results of pre and post knowledge questions (N=94)

Question	Pre survey mean (*SD*)	Post survey mean (*SD*)	Paired *t*-test
What drugs can be detected in the roadside test?	2.6 (1.3)	2.3 (1.3)	$t(75)=2.4$; $p=.021$*
Drugs may increase the risk of a crash by…	4.4 (1.0)	4.5 (1.0)	$t(84)=0.9$; $p=.352$
Penalties for someone caught drink driving more than once?	1.7 (0.1)	1.7 (0.1)	$t(72)=0.4$; $p=.694$
Overall score for knowledge section.	13.1 (2.7)	13.4 (2.5)	$t(84)=1.6$; $p=.114$

* Statistically significant at $p<.05$

Table 4. Results of pre and post survey attitude statements (N=94)

Favourable statements	Pre survey % agreed (95%CI)	Post survey % agreed (95%CI)	% improvement
There are no excuses for drink driving	87.0% (80.1-93.9)	88.0% (81.0-95.0)	1.1%
The legal BAC (.05) is too high	7.6% (2.2-13.0)	23.5% (14.3-32.7)	209.2%*
People who are caught drink driving should lose their licence	44.2% (33.7-54.7)	53.7% (42.9-64.5)	21.5%
Unfavourable statements	**Pre survey % disgreed (95%CI)**	**Post survey % disagreed (95%CI)**	**% improvement**
Drink driving is not as dangerous as speeding	96.7% (93.1-100.0)	92.8% (87.2-98.4)	-4.0%
I'm a better driver after I've had a few drinks	100.0% (100.0-100.0)	100.0% (100.0-100.0)	0.0%
Some people can drink and drive safely	84.8% (77.5-92.1)	92.8% (87.2-98.4)	9.4%
There are times when drink driving is ok	84.8% (77.5-92.1)	88.0% (81.0-95.0)	3.8%
It's ok to drive after a few drinks	73.9% (64.7-83.1)	82.9% (74.8-91.1)	12.2%
You shouldn't be fined if you're a little bit over the limit	81.3% (73.3-89.3)	81.5% (73.0-90.0)	0.2%
Drink driving isn't as dangerous as the police say it is	88.6% (82.0-95.2)	90.2% (83.8-96.6)	1.8%
I'm more careful when I drive after drinking	83.3% (75.6-91.0)	84.3% (76.5-92.1)	1.2%
The legal BAC (.05) is too low	77.5% (68.8-86.2)	81.9% (73.6-90.2)	5.7%
I can drink more than others and still be ok to drive	89.0% (82.6-95.4)	90.2% (83.8-96.6)	1.3%
People used to drink drive in the past and it wasn't a problem	88.9% (82.4-95.4)	88.9% (82.1-95.7)	0.0%

* Indicates no overlap in 95% confidence intervals and, therefore, statistical significance

Multiple correct responses were possible for three knowledge questions, which meant that participants received a score rather than a correct or incorrect result. Table 3 shows that there were no statistically significant differences between the numbers of correct responses for the pre and post surveys for knowledge of how drugs increase the risk of a crash or the penalties for someone caught drink driving more than once. However, participants made statistically significantly fewer correct responses in the post survey compared to the pre survey regarding the specific drugs that can be detected in a roadside test. This indicates a decrease in their knowledge of this information following course completion.

Participants were given an overall score out of 18 for all correct responses for the entire knowledge section (single and multiple correct responses combined). This gave an indication of the overall knowledge that they had before and after the course and whether the course had led to an improvement. The number of correct responses for the overall score did not statistically significantly differ between the pre and post surveys.

Percentages of participants who agreed with three statements favourable to safe driving attitudes (i.e. oppose drink driving) and percentages who disagreed with eleven statements unfavourable to safe driving attitudes (i.e. support drink driving) are compared between the pre and post surveys in Table 4. There was a large increase in participants

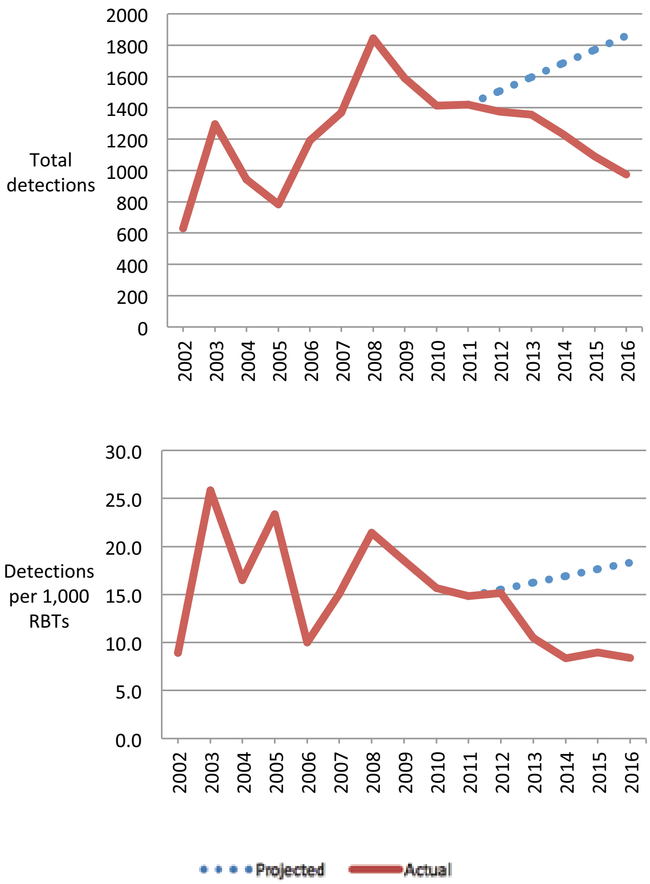

Figure 1. Actual compared to projected (based on 2002 to 2011 trends) total drink driving detections (a) and drink driving detections per 1,000 RBTs (b), in the ACT for calendar years 2002-2016

who agreed that the legal BAC (.05) is too high (209.2%) and this was statistically significant. None of the differences between the surveys for the other attitude statements were statistically significant.

The number of agreed responses to favourable statements and disagreed responses to unfavourable statements were totaled for each participant to give them a score out of 14. This gave an indication of their overall attitudes to drink driving before and after the course and whether the course had led to an improvement. The mean overall score for drink driving attitudes increased statistically significantly from 10.7 (SD=1.9) in the pre survey to 11.3 (SD=2.2) in the post survey (paired-samples t-test, $t(80)=3.2$; $p=.002$).

Effect of the courses on drink driving detections in the ACT

The number of persons detected drink driving in the ACT increased by 193.0% between 2002 and 2008, but decreased by 47.1% between 2008 and 2016 (see Figure 1(a)). The average increase between 2002 and 2011 was 88 detections per year and this was applied to the years 2012 to 2016. This provided a projected model of detections for 2012 to 2016. If the upward trend of 2002 to 2011 had continued, there would have been 1860 detections in 2016. The actual number declined to 975.

RBTs conducted in the ACT increased by 65.1% from 70,541 in 2002 to 116,490 in 2016. This would be likely to have increased the number of drink driving detections over this period. Therefore, to provide a better indication of trends in drink driving detections (particularly as a proxy measure of overall drink driving), the rate of detections per 1,000 RBTs conducted was calculated for each year between 2002 and 2016 and is provided in Figure 1(b). There was a lot of variance from year to year between 2002 and 2008, but overall the rate fell slightly from 8.9 in 2002 to 8.4 in 2016 (5.6% decrease). Between 2002 and 2011, there was a slight

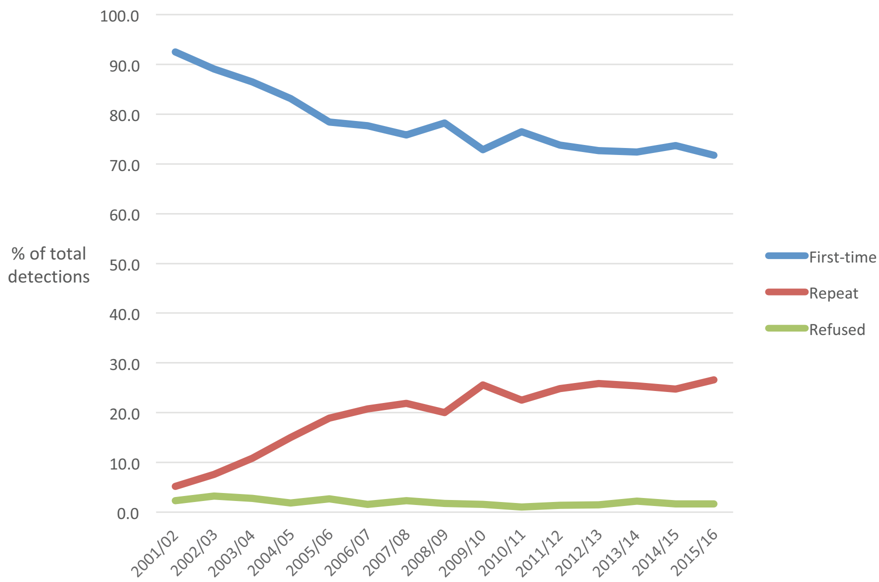

Figure 2. ACT drink drive offenders, financial years 2001/02 to 2015/16

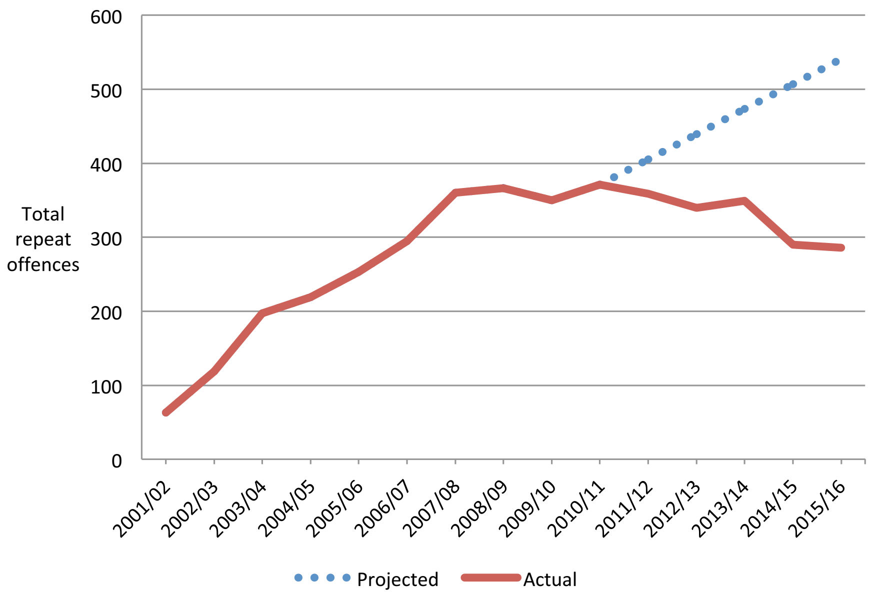

Figure 3. Actual compared to projected (based on 2001/02 to 2010/11 trends) repeat drink driving offences in the ACT, financial years 2001/02 to 2015/16

increase in the average rate of 0.7 detections per 1,000 RBTs per year. This rate of increase was applied to the years 2012 to 2016 and the projected trend is provided in Figure 1(b). Again, it appears that the actual rate of detections per 1,000 RBTs in 2016 (8.4) was lower than it would have been if the 2002 to 2011 trend had continued (18.3).

Detections by type of offence (first, repeat, refused to provide a sample) are presented in Figure 2 as proportions of total detections for each financial year (2001/02 to 2015/16). First offences declined from 92.5% in 2001/02 to 71.7% in 2015/16 (overall decrease of 22.5%). Persons who refused to provide a sample made up a small proportion of total detections throughout the period (2.3% in 2001/02 down to 1.7% in 2015/16, overall decrease of 26.1%). Of interest were repeat offences, which were low (5.2%) in 2001/02 but increased over time (to 26.6% in 2015/16, overall increase of 411.5%), which is likely due to the decrease in the proportion of first-time offenders in the population.

Figure 3 shows that the highest total number of repeat offences occurred in 2010/11 and then there was a decrease of 22.9% by 2015/16. The average increase was calculated to be 34 repeat offences per year between 2001/02 and 2010/11 and this was applied to the years 2011/12 to 2015/16 to provide a projected trend. The number of actual repeat offences of 286 in 2015/16 was considerably smaller than the projected number of 541.

Discussion

The present study evaluated the capacity of ADACs currently provided in the ACT to achieve the desired outcomes. According to KPIs, the number of courses delivered, participants enrolled, participants in attendance, students per course and participants completed have all increased between 2012 and 2014 and remained consistent between 2014 and 2016. The percentage of attendees who completed the course increased from 94% in 2012 to 98% in 2016 and 99% in the first half of 2017. Survey results indicated a small improvement in the general attitudes of attendees of ADACs towards drink driving following course completion. However, knowledge of drink and drug driving information did not improve. Also, the introduction of ADACs has correlated with a reduction in drink driving detections (and possibly overall drink driving behaviour) in the ACT between 2012 and 2016.

It may have been expected that the increasing number of participants attending ADACs would have increased the work load for the course providers. However, as the number of participants increased, the providers were able to increase completion rates from 94% to 98% over the same period. This is a very positive finding, and suggests that they have been able to maintain a strong standard in course delivery. They also had the capacity to increase the number of courses they delivered in order to accomodate the additional participants. This meant that they were able keep the average number of participants in attendance per course at around 10 for 2014, 2015 and 2016. This is consistent with literature relating to best practice for driver education and behaviour change programs (Bukasa et al., 2008; SUPREME, 2007), whereby the general recommendation is that group size should be no larger than 10 persons in order to facilitate discussion and interaction.

It should be noted in relation to KPIs that the Alcohol Ignition Interlock Program was introduced in the ACT in June 2014. Individuals who qualify for either a mandatory or voluntary interlock condition on their probationary licence are still required to undertake an ADAC. However, it is possible that this program may have reduced the number of individuals attending an extended ADAC because it deterred them from repeat drink driving behaviour. Therefore, this may have led to slight reductions in the numbers of participants who would otherwise have been enrolled in, attended or completed the extended courses since the introduction of the program in June 2014.

The results of the surveys were mixed. Firstly, the number of ideal responses only increased between the pre- and post-course surveys for one attitude statement (The legal BAC of .05 is too high). There were no significant increases in correct/ideal responses for any of the other individual survey items (knowledge or attitudes). This could be due to a high level of knowledge and safe attitudes by ADAC attendees to begin with, or the items being relatively easy to identify the correct/ideal response. Indeed, between 80 and 100% of participants gave correct/ideal responses to 14 out of 20 single response items in the pre-course survey. Therefore, there was not much room for potential improvement on these items. Secondly, one knowledge question (What drugs can be detected in the roadside test?) actually decreased. It is not known why the knowledge of attendees of this information would have decreased. Finally, the overall knowledge (total of all knowledge items) of attendees did not improve following ADAC completion. It is not clear why knowledge did not improve. But it should not necessarily be interpreted as a limitation of the ADAC program. Such specific information may just be hard for attendees to memorise, particularly if there are no assessments required for successful completion of the course (currently attendance is all that is required in order to complete the course). It is also likely to be at least partially due to limitations in the survey methods. For example, there was a large amount of information provided in the course but only nine specific questions were included in the survey to assess whether participants had improved their knowledge. These nine questions may not have been best for doing this and others may have possibly been better. It is also possible that participants already had good knowledge of drink and drug driving information and that their drink/drug driving behaviour was not through ignorance of regulations and/or risks but rather that the background to their offending was attitudinal. If this was the case, then the small improvement in the overall attitudes (total of all attitude items) of ADAC attendees towards drink driving is a positive result. However, given there were further limitations in the survey methods (detailed in the Limitations section below), it is likely that this result was unreliable. It should be noted, however, that the ability of other similar educational and behavioural programs to change attitudes has been demonstrated (Dawber and Dawber, 2013; Wilson et al., 2017).

The finding that drink driving detections in the ACT were increasing from 2002 until 2011 when ADACs were implemented, after which they have been decreasing, is positive. ADACs may have correlated with the reduction in detections (and possibly a reduction in overall drink driving behaviour based on the reduction in detections per 1,000 RBTs) through a reduction in repeat drink driving offences in later years as repeat offenders would have been increasingly likely to have attended an ADAC for their first offence. However, caution should be used in drawing this conclusion, as examining trends in drink driving detections is an indirect way to examine the extent of overall drink driving and the findings do not demonstrate a direct causal effect between ADACs and the reduction in drink driving detections. The observed reduction in detections is likely to be at least partially due to other factors, such as other drink driving countermeasures that were implemented during this period. The Alcohol Ignition Interlock Program was introduced in the ACT in June 2014 and this may have contributed to reductions in repeat drink driving detections. It could also be due to increased penalties for offenders (i.e. fines, demerit points, licence sanctions, prison), public education campaigns or economic factors. The use of total drink driving detections was a limitation of this study. A better way to examine the direct effect of ADACs on attendees, would be to obtain data on any subsequent drink driving offences they committed. Such data could not be obtained for the present evaluation of the ADAC program but have been used in evaluations of other similar programs (Ma et al., 2015; Wickens et al., 2016) to show that they reduce drink driving recidivism.

Limitations

It should be noted with regard to the surveys, that the sample that was recruited (*N*=94) was small for assessing statistical significance but reasonable given the limited time frame of the project. It is possible that improvements in other individual knowledge and attitude items would have been found with a larger sample. A larger sample would be ideal for future evaluations of the ADAC program (or other such programs), however, given the number of attendees at the courses (average around 10 per course), survey data would need to be collected for several more months. Additionally, for confidentiality reasons, demographic information (age, gender, etc.) of all ADAC attendees since the program began were not provided to the authors. Therefore, it was not possible to compare the survey participants to the overall ADAC attendees. As such, the survey participants and results may not have been representative of all ADAC attendees but, given the 100% response rate, it is likely that the sample was indicative of current attendees. Future research could endeavour to establish the representativeness of survey participants.

Also in terms of the surveys, it may have been easy for participants to pick the responses that would be considered correct or ideal by evaluators for at least some items. Therefore, there may have been a degree of social desirability bias in the results, whereby participants responded according to what they thought evaluators would consider correct or would be viewed more favourably (particularly for attitude items) whether that was their opinion or not. This may have biased the results towards higher percentages of correct/ideal responses. As mentioned earlier, between 80 and 100% of participants gave correct/ideal responses to 14 of 20 single response items in the pre-course survey.

Research by Clark, Oxley, O'Hern, and Harrison (2015) has stated that appropriate and measureable variables should be collected and available for robust evaluation of offender programs in the immediate and long-term future. This report was not able to examine whether the observed change in attitudes was maintained in the longer-term by participants. This was because the post-course surveys were administered immediately following ADAC completion. Therefore, it is possible that any improvements in the attitudes of participants may be lost with the passing of time since they attended the course. If there is a desire to understand the longer-term impact of ADACs, or of any such programs, a follow-up survey could be sent to participants after a period of time had passed (e.g. 3 to 6 months).

Conclusions

Based on the findings of this evaluation, the overall conclusion is that the ADAC program in the ACT has been performing well since its inception. A majority of attendees successfully complete the courses and they possibly contribute to reducing drink driving, although their effect on the knowledge and attitudes of attendees remains unclear. These findings provide support for the ongoing provision of the ADAC programs, particularly when combined with traditional legal sanctions.

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Appendix A – Questions in the pre- and post-course surveys

Age: ___________

Gender: Male Female

Knowledge

What is the BAC limit for a fully licensed driver in the ACT? ___0.05__

What drugs can be detected in the roadside test? (list them)

Methylamphetamines (also ice, speed, etc.)________________

Cannabis (also THC, Pot, Weed, etc.)________________

Ecstasy (also MDMA)________________

How long does it take the body to remove one standard drink (10 grams) of alcohol, on average?

_____One hour____

Methylamphetamine can be detected in your system for at least 24 hours after using.

True False

At a BAC of .05 how much does the risk of having a crash increase?

None Twice as likely 5 times more likely 10 times more likely

Drugs may increase the risk of a crash by (circle all that are true):

Increasing attention Improving reaction times Risk taking

Over confidence Erratic behaviour Increased care

Reduced concentration

What are the penalties for someone caught drink driving more than once?

Fines, disqualified licence, prison, loss of demerit points________________

Drinking coffee or energy drinks is a good way to sober up before driving.

True False

After a big night of drinking you can still be over the limit when you wake up the next day.

True False

Attitudes

Favourable statements

There are no excuses for drink driving Agree Disagree

The legal BAC (.05) is too high Agree Disagree

People who are caught drink driving should lose their licence Agree Disagree

Unfavourable statements

Drink driving is not as dangerous as speeding Agree Disagree

I'm a better driver after I've had a few drinks Agree Disagree

Some people can drink and drive safely Agree Disagree

There are times when drink driving is ok Agree Disagree

It's ok to drive after a few drinks Agree Disagree

You shouldn't be fined if you're a little bit over the limit Agree Disagree

Drink driving isn't as dangerous as the police say it is Agree Disagree

I'm more careful when I drive after drinking Agree Disagree

The legal BAC (.05) is too low Agree Disagree

I can drink more than others and still be ok to drive Agree Disagree

People used to drink drive in the past and it wasn't a problem Agree Disagree

Making Evidence-based Crash Risk Estimation Routine by using the SESA Process

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Key Findings

- The case studies presented in this paper demonstrate how more robust road safety assessments are possible using the SESA process and various crash prediction tools
- This process can be used to estimate the all-injury and fatal-and-serious injury crash risk at an existing intersection and for various improvement options, even when the intersections have complex and unusual layouts.
- That new crash risk assessment methods like X-KEMM-X can be incorporated into the process to develop even better predictions of expected severe crash risks.

Abstract

Achieving safe system or vision zero outcomes at high-risk urban intersections, especially priority cross-roads and high-volume traffic signals, is a major challenge for most cities. Even after decades of crash analysis and improvement works many of these intersections still perform poorly. While best practice for optimising the efficiency of intersections requires the use of modelling tools, like Sidra, this is rarely the case with optimising road safety outcomes. This is despite the large number of evidence-based safety analysis models and tools that are now available to understand intersection crash risk. This paper outlines the SESA (Site-specific Evidence-based Safety Analysis) Process that has been developed to enable transport professionals to estimate and predict crash risk at intersections and other sites. This process utilises existing crash risk estimation tools (based on crash prediction models and crash reduction factors), relevant road safety research, crash severity factors, professional judgement and crash data to predict the underlying crash risk at intersections (and other sites) and the effectiveness of improvement options. The output includes both the number and return period of 'all injury' and 'fatal and serious injury (FSI)' crashes for each option. The paper includes three applications of the process to high risk intersections in three New Zealand cities, consisting of two priority cross-roads and one high speed roundabout. The case studies demonstrate how the process can be used to assess intersection features and improvement options that are not covered within the available crash estimation tools.

Keywords

Evidence-base crash analysis, crash risk estimation, crash prediction models, safety performance functions (SPFs), X-KEMM-X

Introduction

The majority of urban crash blackspots and many rural blackspots occur at high risk intersections. Even after decades of crash analysis and improvement works, many of these intersections still perform poorly. There is a need for more detailed crash risk analysis to understand the underlying crash risk at these intersections and to assess the effectiveness of improvement options and particularly those that achieve vision zero outcomes.

Best practice in crash risk estimation does not currently require the same depth of analysis as when estimating travel time and vehicle operating costs, using tools like Sidra. It is still fairly common for professionals to 'estimate' the likely change in crashes (usually reductions) based on their 'safety experience'. At best, evaluations reference crash reduction factors and apply these to historical crash data, which in many cases does not accurately reflect the likely trend in future crashes. Only in rare situations does the crash risk estimation involve a detailed crash modelling exercise. Safety evaluations of larger transport projects (Oppenhius and Paris 2000 and Muirson, 2006) indicate that transport engineers are not particularly good at estimating crash benefits. This is likely to be due to the limitations in the crash analysis methods being used.

But why are less robust crash risk estimation methods still being used? There are four fundamental issues: 1) in many jurisdictions there is no requirement (or process) for estimating crash risk using crash prediction (evidence-based) methods, 2) many transport professionals are unaware of the evidence-based tools that are available, 3) few have experience in using such tools and 4) those that have used such tools may have run into difficulties using them, as the tools rarely cover all the crash causing factors present at complex existing intersections and innovative upgrade options.

This paper presents the SESA Process and how it has been applied to intersections in New Zealand. This process can be used to undertake more robust crash risk estimation. Variations of this process have been applied at over a dozen intersections across New Zealand and Australia. The results of a SESA process assessment have many applications, including economic appraisal, public consultation, understanding design compromises and assessing how close various improvement options are to achieving safe system. It is particularly useful when there are a large number of improvement options and it is important to understand the safety outcomes that each may achieve.

To do a robust assessment, analysts must first become familiar with the basic crash estimation tools that are available and of other road safety research. In terms of the basic crash estimation tools, there have been numerous toolkits developed for intersections and other sites that have emerged internationally over the last 20 years. These include Urban Crash Risk Assessment Tool (UCRAT) in Australia (developed by VicRoads), SafeNET in the UK (developed by TRL). In the USA, 1) ISATe (for freeway interchanges) and the 2) the Highway Safety Manual (HSM) analysis software. There are also a number of lesser known crash prediction tools, including the traffic signals crash prediction toolkit developed in New Zealand. Many of these tools can be calibrated to local conditions. It is preferable to use tools that estimate crashes rather than produce risk scores, although the latter can be useful when comparing the effectiveness of various improvement options.

Specialised tools can also be readily developed for each jurisdiction using crash prediction models (also called safety performance functions, SPFs), crash (or accident) modifying factors (CMFs and AMFs) and crash/accident severity factors (SF). In Australasia, New Zealand has the largest repository of crash prediction models. Many of these models are contained within the 'Crash Estimation Compendium' (NZ Transport Agency, 2018). Calibration of these models to Australian conditions has already been undertaken for a number of intersection types. Most Australian State and Territories have crash reduction factor tables for common road features and countermeasures, which can easily be converted to crash modifying factors. Where there is limited local crash modifying factors there are a number of international sources of crash modifying factors, including the CMF Clearinghouse (USA), the Highway Safety Manual (AASHTO, 2010) and the Handbook of Road Safety Measures (Elvik et al. 2009) developed in Europe from international research.

Site-Specific Evidence-Based Safety Analysis (SESA) Process

The SESA process has been developed and refined for predicting crashes at a site or intersection level. The intention is to try and understand the underlying injury crash risk at a site and the likely benefits of upgrade options in reducing both injury and trauma (fatal and serious) crashes.

At an intersection or site level, crash observations (from historical records) can be highly stochastic (random), and may differ to the predictions that are made from crash prediction models, which in most cases better reflect the underlying crash risk. At the urban network level, as might be observed across a dozen or more major intersections, the sum of the crash predictions is normally closer to the sum of the crash observations, due to some sites having higher and other sites having lower observations to the underlying crash risk (Turner, 1995). Many network level tools such iRAP rely on this averaging-out effect. At an intersection level, care needs to be taken when relying on crash observations. In some cases, a high number of crashes may reflect a higher level of risk while at others it may be due to random fluctuations. Hence analysts should tread carefully when using previous crash observations when assessing the safety of intersections and improvement options.

Ideally at the intersection level more detailed crash prediction models and crash modifying factors need to be used, when compared to safety analyses that are undertaken at a network or corridor level. In some cases, network level analysis relies primarily on the traffic volumes, intersection control and number of arms. However, even with the current suite of crash prediction models and crash modifying factors available across New Zealand/Australia (NZ Transport Agency, 2018) and in North America (Highway Safety Manual, AASHTO, 2010) there are a number of localised risk factors that are still not well understood. So especially for complex and unusual intersection layouts the crash observation is often considered in the assessment. The empirical Bayes approach allows a crash prediction to be developed that incorporates the crash history. The weighting placed on the prediction and the crash history depends on the confidence the analyst has in each risk estimate. In some cases, only the crash history is used while in many cases only the crash prediction.

SESA is a process that can be used to develop crash risk estimates for complex intersection layouts and innovative upgrade options (eg. signalised roundabouts, channelised priority intersections and displaced left turn traffic signals) not covered within the current crash prediction toolkits. Given the safety judgements that need to be made through the process, the assessment often requires input from specialised road safety engineers with design and research experience. Figure 1 shows the typical SESA process.

Many of the crash risk modelling tools predict all-injury crashes. To estimate the risk of fatal and serious injury crashes (FSI) or deaths and serious casualties (DSI), there is a need to use crash severity factors. Crash severity factors can readily be developed from historical state-wide crash databases, by intersection type, speed limit, road user involved and crash type. In New Zealand severity factors are available in the Crash Estimation Compendium (NZTA, 2018), the High Risk Intersection Guide (HRIG, NZTA, 2013) and High Risk Rural Road Guide (HRRRG, NZTA 2011).

Crash severity factors can also be developed using kinetic energy models like X-KEMM-X (Jurewicz et al., 2017). How to use X-KEMM-X to develop severity factors is discussed in Case Study 2. In some jurisdictions crash prediction models may also be available for fatal and serious injury crashes. For example, the ANRAM models developed in Victoria.

Case Studies – Applications of the SESA Process

The SESA process has now been applied in excess of a dozen different sites (all intersections), including priority cross-roads, complex traffic signal layouts (e.g. two closely spaced traffic signals) and multi-lane roundabouts. At the majority of these sites there have been in excess of four improvement options. Improvement options are often developed to increase intersection capacity. Options considered include, signalised roundabouts, standard traffic signals, displaced right turn traffic signals, grade separation, three-lane circulating roundabouts and restricted turn options.

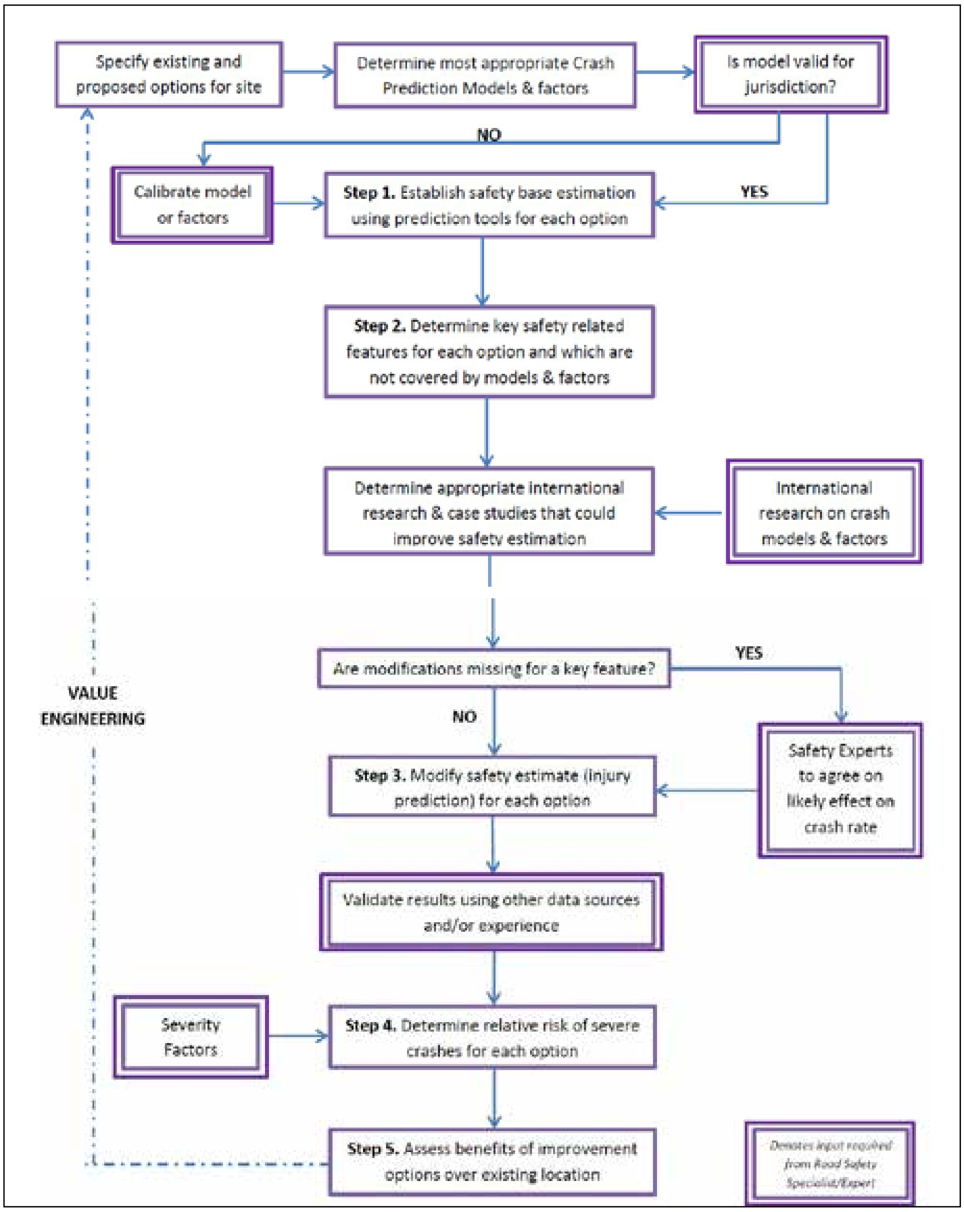

Figure 1. Flowchart of SESA Process

To demonstrate the application of SESA process, three studies have been selected from three different cities across New Zealand, from Christchurch, Tauranga and Nelson. The following summary introduces each of the three intersections along with, why the site is being upgraded, its current intersection control and the main types of upgrade options.

1. Hampden Street/Waimea Road Priority Cross-road (Nelson)
    a. Upgrade required to reduce bicycle crashes
    b. Upgrade options include traffic signals and left-in and left out restrictions.
2. Breens/Gardiner/Harewood Road Priority Cross-road (Christchurch)
    a. Upgrade required to address community concerns, especially pedestrian crossing risk across dual carriageway (Harewood Road);
    b. Upgrade options include traffic signals, turning restrictions, road diet and signalised pedestrian crossing.
3. Elizabeth Street/Takitimu Drive (two circulating-lane) Roundabout (Tauranga)
    a. Upgrade required due to capacity improvements on Takitimu expressway;
    b. Upgrade options include 3-lane roundabout, traffic signals and signalised roundabout.

The following sections provide more detail on each intersection safety study and the expected safety outcomes from the intersection upgrade options. This includes the 'before and after' predicted 'all injury' and 'fatal and serious injury' crash rates for the current intersection and each of the intersection upgrade options (Step 1). The before and after upgrade crash rates are also expressed as return periods. For example, if the return period is one injury crash every 2 years or 24 months, then on average an injury crash is expected to occur every 2 years. So, in ten years, the intersection is expected to have on average five injury crashes. Obviously, a long return period is best as this indicates that on average crashes will occur less often.

Case Study 1: Hampden Street/Waimea Street Priority Crossroad Upgrade

This first study is focused on an intersection that has a number of crashes between motor vehicles and bicycles. With less crash prediction models for bicycle involved crashes this does add an additional challenge. Bicycle-involved crash models are only available for some intersection types.

The Hampden Street Intersection is located on Waimea Road, which is an important and busy regional arterial road in Nelson's transport network. This corridor connects the Nelson Central Business District with destinations to the south. The intersection (see Figure 2) comprises a crossroads priority controlled intersection with a give-way control on the Hampden Street approaches. The intersection has a flush (painted) median, cycle lanes and right turn bays. All approaches have down hill grades, except the northern approach which is relatively flat. The signalised pedestrian crossing is located 30m north of the intersection. Queues from the crossing extend back across the intersection. Hampden Street Primary School and Nelson College High School are situated close to the intersection. A reduced speed of 40km/h is operative during the 8:15-9:00 am and 2:55 to 3:30 pm periods.

At Waimea Road/ Hampden St intersection there have been 26 reported crashes in the past ten-year period. This includes three crashes resulting in serious injuries, 11 minor injuries and 12 crashes without injury. The site-specific problems are:

- Seven of these crashes involved cyclists (27%), with two serious injuries and three involving school children.
- A high proportion (31%) of crashes involved a driver turning right into the Hampden Street western arm and colliding with a vehicle heading north on Waimea Road (NZ crash type LB right turn agent or right turn opposing).
- The two serious injury crashes were cyclists travelling through on Waimea Road being hit by drivers turning right into Hampden Street West (crash type LB).
- The third serious crash involved a vehicle travelling straight through on Hampden Street being hit by a straight through vehicle on Waimea Road.

Of the seven cyclist crashes, six were because of two movement causes, either vehicles travelling south on Waimea Road and turning right to Hampden Street or vehicles travelling west on Hampden Street crossing straight through the intersection. The queued traffic from the pedestrian crossing does restrict the visibility that drivers have to cyclists on Waimea Road when turning right into Hampden Street or travelling straight through on Hampden Street. Another exacerbated factor is the high speed of cyclists travelling north on Waimea Road, who are travelling down a steep grade.

Figure 2. Current Layout of the Wimea/Hampden Intersection

A review of cycle crashes at other priority cross-roads across New Zealand was undertaken. There are very few other priority intersections with seven or more cycle crashes or two serious cycle injury crashes in the last ten years. Hence why this intersection requires improvements to reduce the cycle crash risk.

A large number of potential improvement options were developed to improve safety at this intersection. A list of the options shortlisted and modelled follows:

- **Option 1** – Priority intersection with banned right-turn from Waimea Road north approach into Hampden Street (install signage).
- **Option 2** – Ban all right turn movements at the intersection so it is left in and left out (LILO) only (install concrete median).
- **Option 3** Ban all right turns and make intersection LILO (left in left out) from the Hampden Street East approach and left out only from Hampden Street West approach (install concrete median and kerb protrusion).
- **Option 4a**: Traffic signals at intersection and parallel pedestrian crossing (remove mid-block pedestrian signals in all traffic signal options).
- **Option 4b**: Traffic signals at intersection with Barnes Dance (scattered) pedestrian phasing.
- **Option 4c**: Traffic signals at intersection with Barnes Dance pedestrian phasing and entry only to Hampden Street East approach.

Step 1 in the SESA process is to determine what crash prediction models are available for the analysis (in the Crash Estimation Compendium, NZTA, 2018). Two different intersection crash prediction models were identified:

1. Urban priority crossroads model (for motor vehicles) and,
2. Urban signalised crossroads model (for motor-vehicles & cyclists).

The crash risk at the mid-block traffic signals was estimated using the pedestrian crossing models and crash modifying factors in the Crash Estimation Compendium. Pedestrian and cycle counts were collected for peak hours, then scaled up to 24-hour count estimates using the tools and factors in Turner et al. (2006).

A few assumptions were made in order to calculate the crash predictions. The assumptions made were:

That the cyclists crash rate at the priority intersection could be estimated using the crash model for signalised intersections. This assumption was necessary as crash models for cyclists are not currently available for priority-controlled intersections. The issue is whether this is a valid crash model for the cycle crash risk at this intersection (more discussion below).

- That the mid-block signalised crossing will be removed for all of the traffic signal options, and that all pedestrians would use the intersection and not cross mid-block.
- Where movements are banned but measures are not put in place to physically stop the movement, it has been assumed that all drivers will obey the signage.

A ’base model’ crash rate was calculated for the existing layout at Waimea Rd/ Hampden St intersection using the crash prediction models for motor vehicles, cyclists and pedestrians.

In Step 2 the main concern was how valid the cyclists crash rates were for this priority cross-road. The three key concerns being 1) using a traffic signal crash model rather than priority crash model, 2) that the main road queuing (due to the pedestrian crossing) was not considered in the crash models, and 3) the speed of cyclists entering the intersection (travelling downhill from the south) is expected to influence crash severity. The output from the model was compared against the reported ten-year crash history to assess validity of the model. Two safety specialists determined that the ’base model’ crash predictions needed to be modified to better reflect the crash history rates.

Table 1. Hampden Street/Waimea Street Intersection Upgrade safety results

	Base	Option 1	Option 2	Option 3	Option 4a/4b	Option 4c
Estimated number of injury crashes per year (motor vehicle only)	1.05	1.02	0.65	0.65	0.81	0.78
Estimated number of injury crashes per year (cyclist v motor vehicle)	0.85	0.70	0.25	0.21	0.37	0.34
Estimated number of injury crashes per year (all)	1.90	1.72	0.90	0.86	1.18	1.12
Estimated return period for injury crashes (years)	0.53	0.58	1.11	1.16	0.85	0.89
Estimated number of FSI[20] crashes per year	0.33	0.30	0.15	0.14	0.19	0.18
Estimated return period for FSI crashes (years)	2.99	3.37	6.85	7.29	5.36	5.68

Based on a review of the crash history, the cycle crash history at other priority intersections across New Zealand and crash causing factors, like speed of downhill cyclists and the queuing through the intersection, it was determined that the intersection had a cycle crash rate well beyond that observed elsewhere in New Zealand. It was concluded by the specialists that the available crash prediction model for cyclists (at traffic signals) was not suitable and hence the injury crash risk from the ten year crash history should instead be used for cyclist crashes at this intersection (Step 3). With seven cycle crashes in total this was considered a suitable number of observations to establish a site crash risk from the crash history. The base crash estimates from the crash models were considered suitable to assess the crash risk for motor-vehicle and pedestrian crashes.

In Step 4 the predicted number of fatal and serious crashes was calculated using the severity factors in the Crash Estimation Compendium. The results of the analysis are shown in Table 1.

The analysis shows that Option 2 and 3 (restricting right turning movements) provide the greatest reduction in the estimated number of injury crashes and fatal and serious injury crashes at the intersection, with each of the Option 4 sub-options still providing improved safety outcomes. Some safety effects are not fully captured in this analysis, such as drivers and cyclists having to use alternative routes (and intersections) due to turning bans. Such effects can reduce the benefit of some options. In this case the effects are minimal compared to the safety benefit at this intersection.

Case Study 2: Breen/Gardiners/ Harewood Intersection Upgrade (Christchurch)

In this recent SESA, Abley were asked to do an independent safety review of a number of intersection improvement options that had been proposed at the Breens / Gardiners / Harewood intersection. Both the Breens Road and Gardiners

Figure 3. Layout of Breens/Gardiner/Harewood Road Intersection

Road legs of the intersection (see Figure 3) are controlled with stop signs and markings. Harewood Road is configured as a four-laned median divided road with right turn bays within the median.

While this intersection does not have a high crash rate over recent years, there is a lot of public interest in what is perceived to be a very unsafe intersection on a key arterial route, especially for pedestrians (school children) crossing Harewood Road. This project had received over 1,000 public submissions with many wanting the intersection signalised.

The scope of the safety assessment was to assess the expected safety performance, particularly in terms of the risk of fatal and serious crashes, of the various options relative to the existing situation. Figure 4 shows that there are a lot of conflicting points at the current intersection due to the number of turning movements and four lanes of traffic on Harewood Road.

The site has had 28 reported crashes in the last 10-year period, with 21 of those crashes being right- angle crashes (no turns, or under NZ coding HA-type crashes). The majority of the crashes were of low severity, with only five injury crashes in the ten years (2.5 injury crashes every five years). There have also been no crashes between pedestrians and motorists, despite safety concerns and observations of risky crossing behaviour.

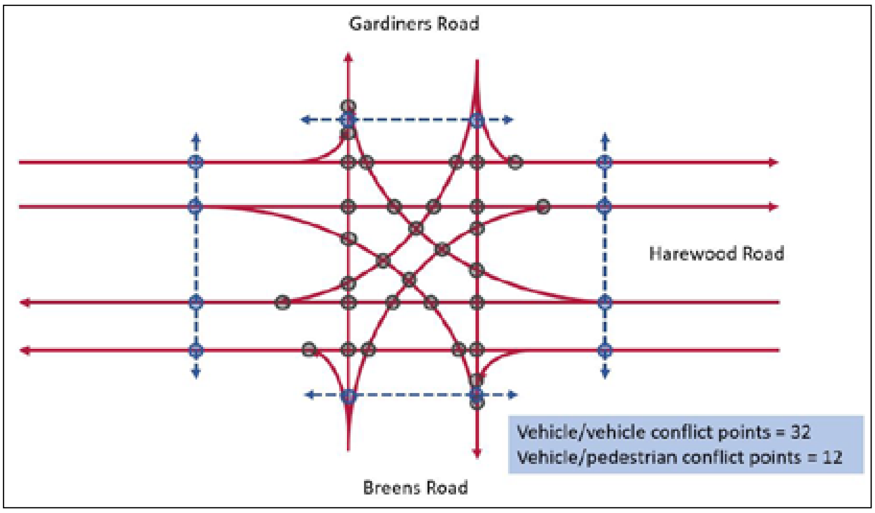

Figure 4. Traffic Conflict Points at current Breens/Gardiners/Harewood Road Intersection

In Step 1 it was established that there are crash prediction models in the Crash Estimation Compendium for urban signalised crossroads and urban priority crossroads. The priority crash model was used to estimate the base crash rate at the existing intersection. The model estimated that there should be on average 2.8 injury crashes in a 5-year period. This compares favourably with the number of crashes observed and so the current intersection is performing as expected.

While the vehicle crash rate may be at the crash levels expected, and there have not been any pedestrian crashes over recent years, there is a major concern from the public that the intersection is unsafe for vulnerable road users and there is a need to install a signalised crossing so that these vulnerable road users, including school children, can safely cross Harewood Road. Hence why the Council are planning to upgrade the intersection to safely accommodate crossing pedestrians (and cyclists). There were three proposed options presented to the public (see Figure 5 and 6) as follows:

- **Option One**: Left-in/ left- out configuration and one single lane in each direction on Harewood Road (road diet), with right-turn movement permitted into Gardiners Road and nearby signalised pedestrian crossing (Figure 5).
- **Option Two**: Signalisation of the existing intersection. The impact of this is likely to be more traffic crossing between Breens and Gardiners, as many drivers currently use alternative routes (Figure 6).
- **Option Three:** Conversion of Harewood Road to a single lane in each direction (road diet) and retain stop control (Figure 6).

From a traffic conflict perspective Option 1 has a lot fewer conflict points (as shown in Figure 5) than the existing intersection and the other two options, although it will push some traffic to do U-turns in the median and onto other intersections. Option 2 has the same number of conflict points and Option 3 has a lower number only due to the single lane in each direction on Harewood Road. This is a major difference between the options that is considered in the crash severity analysis.

In this case the crash models that were available were suitable for the options (Step 2) and so no adjustment was required to the base estimates (Step 3). This was also confirmed by the validation of the crash history and crash prediction for the existing priority cross-roads. Turning bands can be modelled by assuming zero flows for the

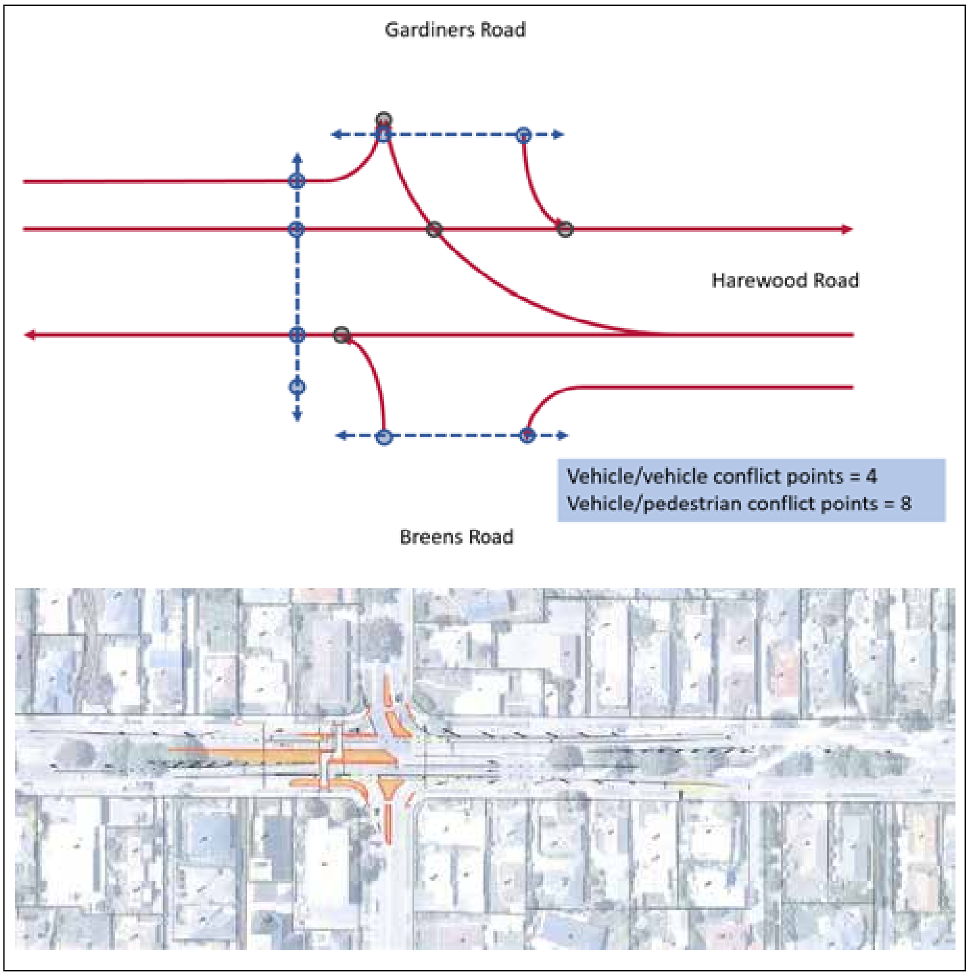

Figure 5. Option 1: Restricting right turn movements and road diet on Harewood Road

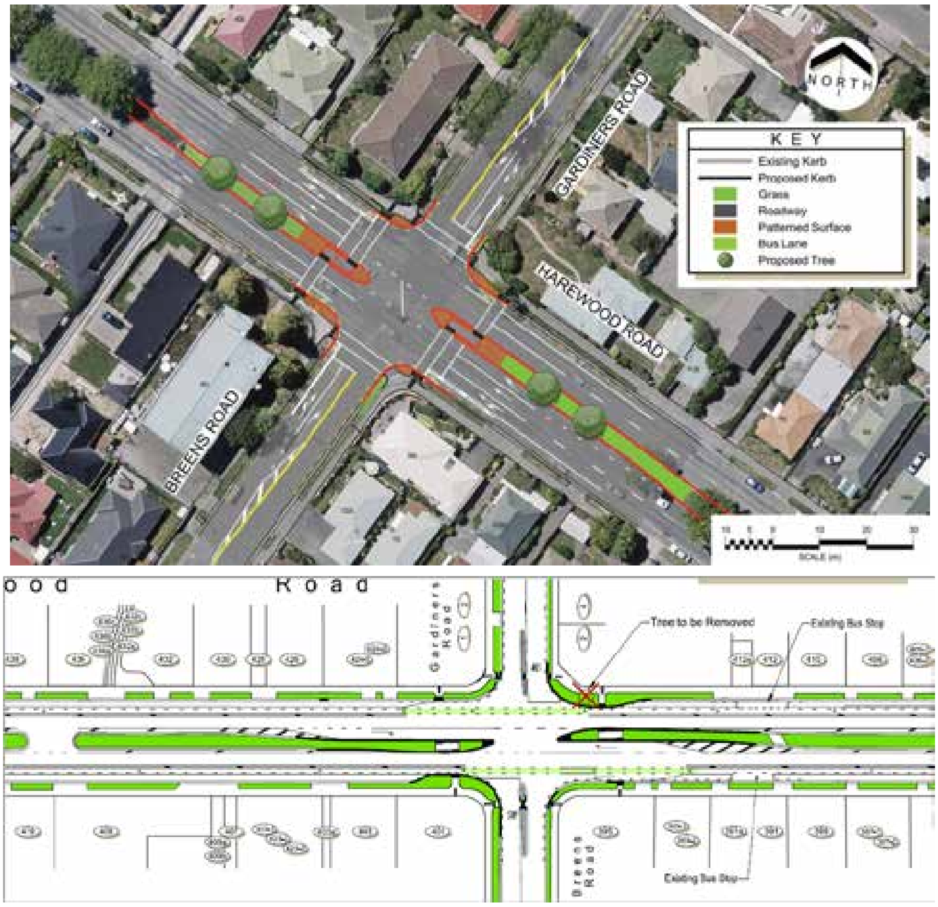

Figure 6. Traffic Signals (Option 2) and Priority with Road Diet (Option 3)

banned movements. While crash prediction tools are available for pedestrian and cycle crashes at traffic signals (Option 1 and 2) and crossing aids (Option 3), the focus of this study was on motor vehicle safety. It is relatively clear that a signalised pedestrian crossing is safer than one with crossing aids only.

Traditionally in SESA, we use crash severity factors to estimate the risk of fatal and serious injury crashes for existing sites and each option. This approach, however, does not adequately take into account the reduction in the number of serious conflicts when traffic movements are banned, as is the case for Option 1, or when a road diet is applied. The removal of most of the crashes involving right turning vehicles and between two straight through vehicles is expected to reduce the overall severity of crashes at this intersection. To take this reduced severity into account we have used the X-KEMM-X kinetic energy model (Jurewicz et al., 2017) in Step 4 to estimate the severity of each conflict point and for each crash type based on speed and impact angle.

Application of the X-KEMM-X method to the existing intersection shows that 20 of the 32 vehicle/vehicle conflict points have a greater than 10% likelihood of producing a serious injury outcome. Overall, the average expected likelihood of a serious injury outcome across all 32 conflict points is 34%. Multiplying the expected number of injury crashes from the crash prediction models by the average expected likelihood of a serious injury outcome can provide an indication of the inherent level of safety of an intersection configuration. For the existing intersection configuration, this is 0.19 high severity crashes (including fatalities) per annum, or approximately 1 every 5 years.

As shown in Figure 5, Option 1 does involve major alterations to the intersection, and results in only four vehicle/vehicle conflict points (compared to 32 for the existing intersection) and eight vehicle/pedestrian conflict

Table 2. Breens/Gardiner/Harewood Intersection Upgrade Safety Results

Option	Expected Injury Crashes per annum	Number of High Severity Conflict Points	Expected High Severity Crashes per annum
Existing	0.55	20	0.19
Option 1	0.38	3	0.10
Option 2	0.78	22	0.38
Option 3	0.55	12	0.13
Safest Option	Option 1	Option 1	Option 1

points. For Option 1 and the other two options the impact on crash severity (Step 4) has been evaluated using a combination of applying the crash prediction model and the X-KEMM-X derived severity values. Table 2 shows the results of the combined analysis.

Case Study 3: Elizabeth Street / Takitimu Drive Roundabout Upgrade

In this study the team were asked to review the relative safety of a number of options to improve the capacity of the existing roundabout (see Figure 7), as it was experiencing congestion during peak periods. The Elizabeth St/Takitimu Drive intersection consists of a two lane, three arm roundabout, with a northbound bypass lane, located on the State Highway 2 (Takitimu Drive) expressway in the city of Tauranga. SH 2 is a major route for freight traffic travelling to and from the Tauranga Port.

There were three main upgrade options with a number of sub-options developed as follows:

Option 1a - Signalised Existing 2-lane Roundabout (Full-time);

Option 1b - Signalised Existing 2-lane Roundabout (Part-time);

Option 2a - Signalised 3-lane Roundabout (Full-time) with widening to the east;

Option 2b - Signalised 3-lane Roundabout (Full-time) with reshaping of central island;

Option 2c - Signalised 3-lane Roundabout (Part-time) with widening to the east;

Option 3 - Signalised T-Intersection.

The part-time (or metered) signalised roundabout options involved managing the volume of traffic entering the roundabout on SH2 in the southbound direction during

Figure 7. Current Layout of the Elizabeth Street/Takatimu Drive (SH 2) Roundabout

peak periods to allow traffic to enter the roundabout and expressway from Elizabeth Street. For the three-lane signalised roundabout options, one option was to widen to the east, but this required land purchase and associated changes to the parking areas and possibly two industrial buildings on Elizabeth Drive. The alternative option, to minimise land take, was to modify the shape of the roundabout central island to accommodate the third southbound lane. The impact of this was to reduce the deflection in the lanes heading south which would increase speeds and may increase crash severity.

In Step 1 it was established that base estimates could be developed using the roundabout and signalised T-intersection (Option 3) crash prediction model in the Crash Estimation Compendium (NZTA, 2018). During Step 2 it was established that the current models could not be used to estimate the impacts of signalising the roundabouts (part-time (metered) or full) or the impact of the cut-through of the central island. Both factors were expected to impact on crash performance of the options.

In Step 3, the signalised roundabout international research was reviewed. A British study on part-time (or metered) and full-time signalised roundabouts was found (CCS, 1997) that looked at both the impact of the signals on all-injury and trauma crashes. The study found that;

- At full time, or continuous, high-speed signalised roundabouts there was an 11% reduction in crashes and a reduction in severity of 44%, compared with an unsignalised roundabout.
- In the case of part-time (metered) signals, an 8% reduction in crashes occurred during operation of the signals, but a 66% increase occurred when the signals were not in operation. No change in crash severity was noted.

To assess the impact of the cut-through central island option (Option 2B) a safety specialist referenced the advice in Arndt (1998) and used professional judgement to estimate the likely crash impacts (Step 3) of the reduced deflection and likely increase in speed caused by the cut-through.

In Step 4 the risk of serious injury and fatal crashes was estimated using the severity factors in the Crash Estimation Compendium (NZTA, 2018) and for the signalised roundabouts from the British research. The crash predictions for each of the capacity improvement options are shown in Table 3**.**

Table 3 shows that the full-time signalised roundabouts have the lowest number of expected injury crashes and more serious crashes (fatal and serious injury). The crash rates for the standard traffic signals (Option 3) is also higher. For capacity reasons the 3-lane roundabout options (2a and 2b) are preferable. There is not a lot of difference between these two options. With the lower costs of Option 2b, where there is no land take, it is the overall best option. However, there are still some safety concerns with the reshaping of the central island and the reduction in the deflection.

Table 3. Elizabeth Street/Takitimu Drive Intersection Upgrade Safety Results

Option	Description	Injury Crash Prediction (5 Years)	Proportion of crashes that are Fatal/ Serious	Fatal and Serious Crash Prediction (5 Year)
Option 1a	Signalise existing roundabout full-time	4.6	7%	0.34
Option 1b	Signalise existing roundabout + part time	7.8	12%	0.90
Option 2a	Signalised Roundabout with 3 lanes + widening to east + full time	4.8	7%	0.34
Option 2b	Signalised Roundabout with 3 lanes + reshaped central island.	4.9	7%	0.36
Option 2c	Signalised Roundabout with 3 lanes + widening to east + part time	8.1	12%	1.04
Option 3	Signalised T intersection	5.4	15%	0.80

Discussion and Conclusions

Despite the increased availability of evidence-based crash estimation tools, the safety analysis of very few intersection upgrade projects receive anywhere near the level of attention that is given to the travel time assessments. One of the challenges is that many of the current road safety analysis tools (based on crash prediction models) are not in a user-friendly format like travel time assessment tools (e.g. Sidra and Paramics). Also, in many situations, it is necessary to model intersection designs that are different to those covered by the available crash estimation toolkits. To make better decisions on the selection of improvement options at intersections it is important to understand with more accuracy the expected road safety outcomes.

The SESA process outlines the various steps that can be followed to produce 'all-injury' and 'fatal and serious injury' crash risk estimates for both standard and complex intersection options, even where the current crash estimation tools do not cover the proposed design (e.g. signalised roundabout). The three studies profiled in this paper demonstrate how this process has been applied to different intersection types and potential intersection upgrade options. Each safety assessment has different challenges, especially when having to extend the crash prediction modelling tools to more complex and uncommon intersection types. Using a consistent process, like SESA with clear decision-making steps, is important in justifying the results of such assessments.

The majority of assessments made using the SESA process do require input from one or more experienced road safety professionals. However, our experience with this type of assessment does indicate that the bulk of the analysis, when the process is followed, can be undertaken by a less experienced person. Hence, we believe that this type of analysis should become common place in the profession and replace some of the less rigorous methods that are often used. More accurate safety assessments are important as they enable transport professionals to clearly present to decision-makers, stakeholders and the general public the safety outcomes that can be expected for various improvement options. In the past it has often been difficult to differentiate between improvement options on safety grounds due to the limitation of the safety analysis methods.

To date the SESA process has not been used to optimise intersection designs to achieve a safe system or vision zero outcome. Going forward this process, combined with kinetic energy models, such as X-KEMM-X, could be used to do a vision zero assessment for each option. This assessment would require a detailed analysis of the various conflict points at an intersection for all road users (using X-KEMM-X and other tools) and either managing speeds and impact angles to reduce the risk of fatal and serious injury crashes to very low levels or eliminating such risk through better design, such as banning turns. Note that X-KEMM-X is still under development and so not all traffic conflicts can be currently assessed. Where a design does not achieve safe system, such an analysis would indicate how close each intersection improvement option is to safe system.

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Safety on Heavily Trafficked Urban Motorways in Relation to Traffic State

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Key Findings

- Casualty crashes on urban motorways have increased by 59 per cent over 10 years;
- Casualty crash rates are lower on managed motorways than on unmanaged motorways;
- Statistically significant association exists between traffic state and number of crashes;
- Higher than expected crashes occur if flow breakdown has occurred or is relatively certain;
- Safety is improved by minimising time of operation in unstable and congested states.

Abstract

Motorways represent seven per cent of the urban arterial road network in Melbourne yet carry 40 per cent of the urban arterial road travel in terms of vehicle kilometres travelled and this percentage is growing. The number of casualty crashes on metropolitan Melbourne motorways has increased over the decade at a faster rate than on other urban roads in metropolitan Melbourne. Police crash reports more often attribute crash cause to traffic conditions and vehicle interactions rather than infrastructure. As urban motorways are generally built to the highest standards, a new way of looking at motorway safety is needed. This led to the formulation of a hypothesis that the dynamics of the traffic flow are a significant contributor to casualty crashes on urban motorways. To test this hypothesis, in-depth analysis was undertaken on metropolitan Melbourne motorways. Crash data was linked to traffic data including vehicle occupancy (a proxy measure for density), vehicle speed and flow. Occupancy was used to categorise the 'traffic states' ranging from free flow to flow breakdown (congestion). Applying a Chi Square Goodness of Fit Test to the linked showed a statistically significant association between traffic state and crashes, with a higher than expected crashes in the traffic states where flow breakdown is relatively certain or has occurred. The results of this analysis can be used to improve safety on urban motorways through the development of Intelligent Transport System strategies to keep the motorway operating at conditions that minimise flow breakdown risk.

Keywords

Crashes, Urban Motorway Safety, Traffic State, Congestion, Managed Motorways, Freeways

Glossary

Bottleneck. A typically fixed location where the capacity is lower than the upstream capacity.

Casualty Crash. A crash where one or more persons are killed or injured. For a crash to be reportable, it needs to have occurred on a road or road-related area open to the public, involved at least one moving vehicle and resulted in one or more persons killed or injured in the crash (VicRoads, 2013).

Congestion. Traffic state where traffic volumes are medium to high and the flow is unstable or broken down with varying speeds and flows. Congestion can occur at occupancies around 18%, however this value is dependent on the site and on the type of detector system used.

Density. Number of vehicles per unit length of lane or roadway at a given instant in time (vehicles per kilometre).

Detector. Device to detect vehicles passing a certain point on the road. Detectors can measure the speed, flow and occupancy on the motorway. There are different vehicle detection technologies including inductive loops, magnetic sensors and infrared detectors.

Downstream. In the direction of the movement of traffic.

Fatal Crash. A crash where one or more persons are killed or die within 30 days of a crash.

Flow (Rate). The number of vehicles passing a given point on a lane, carriageway or road per unit of time, typically expressed in vehicles per second or an equivalent number of vehicles per hour.

Flow Breakdown. Abrupt transition from a 'free flow' to a 'congested' state that lasts for a defined period of time (for this paper the defined period is at least 15 minutes). In this state free flowing traffic experiences significant and sudden reduction in speed, with a sustained loss of throughput and may result in queuing and stop-start conditions.

Flow Breakdown Risk (FBR). The risk of flow breakdown.

Free Flow. The condition where traffic volumes are relatively low, flow is stable and there is very low risk of flow breakdown.

Lane Filtering. Situation when a motorcycle or scooter travels at a low speed through stopped or slow-moving traffic. Lane filtering is legal in Victoria.

Lane Splitting. Situation when a motorcycle or scooter travels at a high speed between moving traffic. Lane splitting is illegal in Victoria.

Level of Service (LOS). Qualitative measure that characterises operational conditions within a traffic stream, usually based on density on motorways. The six levels of service are from A to F with LOS A representing the best operating conditions and LOS F the worst.

Managed Motorway. Motorway managed with CITY-WIDE COORDINATED RAMP METERING (CWCRM) signals controlling demand in the system. May also include management with other tools. The presence of a ramp meter does not necessarily mean that the motorway is a managed motorway. A managed motorway has a coordinated ramp metering system controlling access to the motorway at every on-ramp and is suitable to prevent flow breakdown and provide sufficient gaps for vehicles. Refer to the VicRoads Managed Motorways Framework for more details (Gaffney, Lam, Somers, Johnston & Boddington, 2017).

Mainline. The main through carriageway as distinct from ramps and collector-distributor roads. This is the carriageway carrying the main flow of traffic and generally passes straight through at an interchange.

Motorway. A divided roadway with no access for traffic between interchanges and with grade separation at all road junctions. It includes urban freeways and tollways.

Occupancy. The proportion of time a length of roadway or traffic lane is covered by vehicles, usually expressed as a percentage. Occupancy is used as a surrogate for density in control systems as it is easier to measure. Occupancy values are related to the detector configuration therefore operational values may vary according to the detector type, size and spacing. Occupancy measures may be normalised to represent a fixed detector footprint to enable comparable results from different technologies and layouts.

Other Injury Crash (Minor Injury Crash). A crash where one or more persons are injured but not admitted to hospital. Excludes crashes in which persons are killed or seriously injured.

Productivity. Mathematical product of flow rate and speed.

Ramp Meter. Traffic signals installed on a motorway entry ramp to regulate traffic onto the motorway to manage traffic flow and prevent congestion and flow breakdown.

Serious Casualty Crash. A crash in which one or more persons are killed or injured. This includes fatal crashes and serious injury crashes but excludes other (minor) injury crashes.

Serious Injury Crash. A crash where one or more persons are injured and admitted to hospital. Excludes crashes where a person is killed or died within 30 days of the crash.

Shock Wave. A moving location within the traffic stream where an abrupt change of traffic conditions occurs, generally with free flow upstream and congested flow immediately downstream of the moving shock wave. It represents a discontinuity in flow-density conditions.

Speed. The distance travelled by a vehicle per unit of time, typically expressed in metres per second or kilometres per hour.

Traffic State. A description of the traffic conditions on the motorway expressed as a function of the speed, flow rate (volume) and / or density (measured by occupancy).

Upstream. In the direction opposite to the movement of traffic.

Introduction

Motorways have traditionally been perceived as safe as they are generally built to the highest safety standards, have restricted access and have a low crash risk in terms of casualty crashes per vehicle kilometres travelled. Casualty crash numbers, however, have been increasing on the motorway network at a faster rate than on other urban roads in metropolitan Melbourne. Similarly, serious casualty crashes (that is, fatal and serious injury crashes) have been increasing on metropolitan Melbourne motorways despite a decrease on other urban roads. Often this increase is masked due to a progressively reducing crash rate resulting from rapid growth in travel on motorways outstripping travel growth on other roads.

The metropolitan Melbourne motorway network represents only seven per cent of the total urban arterial road network in terms of lane kilometres, yet it carries 40 per cent of the urban arterial road travel, measured in terms of vehicle kilometres travelled. The reliance on the motorway network is increasing, with an estimated future likely share of 50 per cent, based on trend extrapolation (VicRoads, 2018). The growing number of vehicles per unit of road space and the addition of more traffic lanes on the urban motorways result in more interactions between vehicles and an increased complexity of the driving task for motorists, particularly during peak periods where disturbances in traffic flow can result in motorists having reduced or no reaction time, requiring emergency braking or lane changing to avoid a collision.

Current road safety programs focus on infrastructure improvements to reduce fatalities and serious injuries, particularly on high speed rural roads. Infrastructure deficiencies are rarely mentioned in the Police crash reports as being causes of urban motorway crashes, rather mention is made about traffic conditions such as 'heavy traffic' and vehicle-to-vehicle interactions such as 'did not see other vehicle'. Given the already high standard of infrastructure on urban motorways, the potential to reduce fatalities and serious injuries through further infrastructure upgrades has been largely exhausted. Provision of new tools and technology solutions to manage traffic conditions may be more beneficial to reduce the casualty crash numbers on motorways than just traditional approaches to improving hard road infrastructure (civil).

New technology capable of measuring the number of lane changes per kilometre per hour has been deployed by VicRoads on some metropolitan Melbourne motorways. Analysis of this data at trial sites has highlighted the increasing complexity of traffic flow dynamics and the corresponding multiple interactions that occur between vehicles, including abrupt braking and lane changing manoeuvres. The required driver response can be challenging, cannot always be realised and at times can exceed the capabilities of the driver, contributing to the increasing number of casualty crashes. These observations are supported by international research. For example, Golob, Recker & Alvarez (2004) identified the adverse safety effects of congested motorways and stated that the casualty crash rate can rise as much as 5-6-fold under flow breakdown (congested) conditions. Kononov, Bailey & Allery (2008) concluded that the number of crashes increases only moderately with increase in traffic on uncongested segments of motorway, but once a critical traffic density is reached then the number of crashes rises at a much faster rate as traffic increases.

These observations have led to the formulation of the hypothesis that the dynamics of the traffic flow, which cause congestion and require complex driver responses, are a significant contributor to casualty crashes on urban motorways. To test this hypothesis, an in-depth investigation was undertaken on metropolitan Melbourne motorway crashes. The investigation looked at crash causation and at the occurrence of casualty crashes in relation to the traffic state. This paper outlines the investigation undertaken, the conclusions resulting from this investigation and makes recommendations for the next steps. The purpose of this research is to provide an evidence-base for a robust problem statement that could lead to the development of suitable counter-measures that stop, or even reverse, the increasing casualty crash trend on metropolitan motorways.

Previous Research into the Dynamics of Traffic Flow and Crashes

Evidence is growing about the relationship between motorway crashes and traffic conditions. Ceder & Livneh (1982) and Martin (2002) observed that single-vehicle crashes decrease as flow increases whilst multi-vehicle crashes increase as flow increases, and that there were variations between day, night, weekday and weekend. Kononov et al. (2008) identified a linkage between the number of lanes on a motorway to the number of conflict points and noted that crash rates increase as the number of carriageway lanes increases.

Overseas and interstate examples indicate that there is likely to be an optimal occupancy range where relatively high flow rates coincide with a low breakdown probability and a low crash rate. Garber & Subramanyan (2001) observed that crashes increase with increasing density, reaching a maximum before the optimal density at which flow is at capacity. Golob et al. (2004) showed a correlation between crash rate and the inherent traffic states as traffic conditions move from free flow to congested conditions (that is, safety decreases as congestion increases). They found that in light free flow conditions the estimated total crashes per million vehicle miles of travel was 1.28. In conditions where the flow approached capacity, the rate was 0.55. Once flow was congested, the rate rose to 2.97 in variable-speed congested flow conditions and to 5.99 in heavily congested flow conditions (refer to Figure 1).

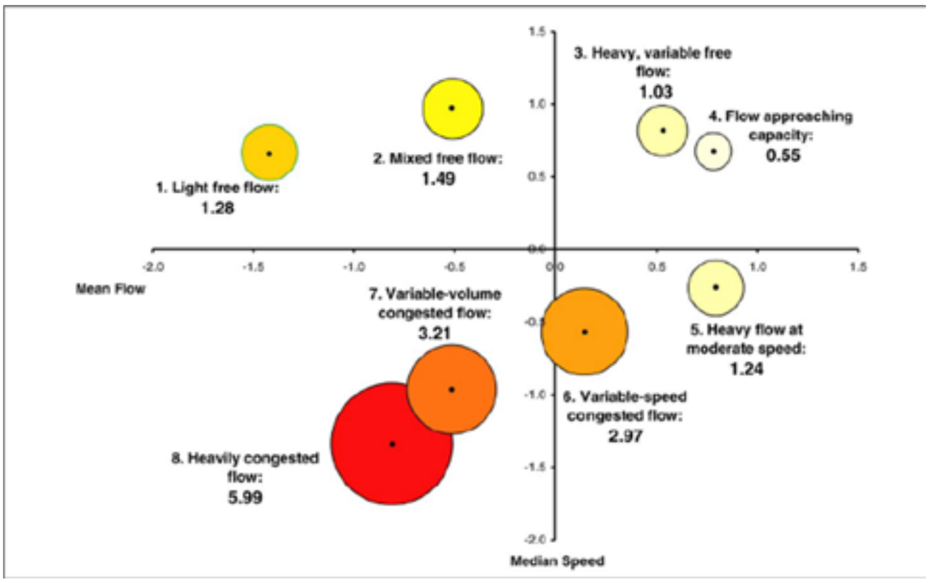

Figure 1. Estimated total crashes per million miles of travel for the eight traffic flow regimes during AM peak hours, plotted in standardised speed-flow space (Golob et al., 2004)

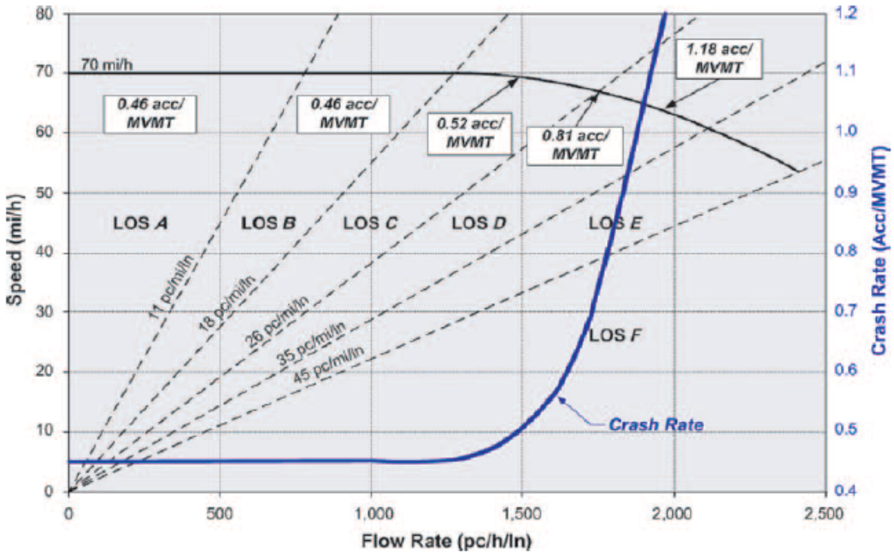

Figure 2. Crash rates relationship to speed, volume, density and Level of Service (LOS) (Kononov et al., 2012)

Kononov et al. (2008) mentioned that once some critical traffic density is reached, the number of crashes begins to increase at a much faster rate as traffic increases and Kononov, Reeves, Durso & Allery (2012) found that there was a critical threshold of speed and density beyond which the crash rate rapidly increases (refer to Figure 2). Zheng (2012) found that traffic conditions had a significant impact on the crash occurrence likelihood, with the likelihood in congested traffic flow being six times of that in free flow conditions and the likelihood in transitioning traffic flow being 1.6 times of that in free flow conditions.

Methodology

Analysis of metropolitan Melbourne motorway casualty crashes was undertaken using Police-reported casualty crashes sourced from the VicRoads Road Crash Information System. A comparison of the long-term trend in casualty crashes on urban motorways with casualty crashes on other urban roads was undertaken using data for the 2007 to 2016 10-year period. A similar comparison was undertaken for serious casualty (that is, fatal plus serious injury) crashes however, due to issues with consistency in the determination of serious injuries between 2006 and 2009, it was not possible to do a 10-year trend analysis so a seven-year period (2010 to 2016) was used instead.

A high-level analysis of metropolitan Melbourne motorway casualty crashes, focused on crash types, vehicle characteristics and time and location of the crashes, was undertaken for the period 2012 to 2016. A comparison of crash rates on selected managed and unmanaged motorways was also undertaken for the same period.

A limitation of this analysis was that recent data could not be used due to an apparent discontinuity in casualty crash data. Between 2016 and 2017, there was a state-wide decrease of 14 per cent in Police-reported casualty crashes. In previous years, the annual change in casualty crashes averaged 0.7 per cent. As a result, the analysis in this report did not include 2017 data.

Detailed crash analysis was undertaken on casualty crashes on the Monash Freeway (a managed motorway) and the Eastern Freeway (an unmanaged motorway) that occurred on the main carriageways between 2013 and 2016. The detailed analysis involved reviewing the images and descriptions provided by the Police for each of the crashes to gain an understanding of the circumstances and causal factors of the crash, to confirm the carriageway (inbound or outbound) on which the crash occurred and to determine the lane in which the crash occurred. Spatial analysis techniques were then used to identify the closest downstream detector for each crash location and speed, volume and occupancy data was extracted for each of the crash locations on the inbound carriageway from the STREAMS application using an interface built in MS Excel. Due to the labour-intensive task of extracting the traffic condition data for each crash, the traffic state analysis focused on casualty crashes for four years of data (between 2013 and 2016) on the inbound carriageways but will be extended in the future to include the outbound carriageways and to include a fifth year.

The average downstream speed, volume and occupancy data in the five-minute period before the crash was then linked to the crash data and the crashes were grouped into five traffic states based on the occupancy. Occupancy is the most important parameter for current coordinated ramp metering on managed motorways in metropolitan Melbourne.
The linking of crash occurrence with occupancy could potentially provide a basis for multi-objective traffic control that aims to maximise safety as well as improving efficiency (Haj-Salem, Farhi, Lebacque & Bhouri, 2016).

The following occupancy ranges, based on flow breakdown probability, were used in this analysis to categorise the traffic state. The VicRoads Motorway Design Volume Guide (Zurlinden, Gaffney & Hall, 2017) provides a detailed description of the flow breakdown probability calculation methodology:

- **Free flow** (<=4.9% occupancy) – low traffic volumes, stable flow and very low flow breakdown risk;
- **Transition** (5% to 9.9% occupancy) – low to high traffic volumes, instabilities and breakdown risk starting to occur due to more interactions between vehicles, including abrupt braking manoeuvres and sudden lane changes at high speeds;
- **A significant level of flow breakdown risk**, i.e. flow breakdown risk (FBR) smaller or equal to around 1% per 15-minute interval or 10% per 3-hour peak period (10% to 14.9% occupancy), declining speeds and decreasing freedom to manoeuvre;
- **Flow breakdown relatively certain**, i.e. flow breakdown risk (FBR) between around 10% and 100% per 3-hour peak period (15% to 19.9% occupancy), lower speeds and limited freedom to manoeuvre;
- **Flow breakdown** (>=20% occupancy).

To determine the statistical significance of the relationship between crashes and traffic state, expected crashes were calculated based on exposure values. Exposure values were obtained from a randomly selected sample of detectors and various dates. These exposure values combine the percentage of time that the motorway was operated in the specified occupancy range and the typical traffic flow rate that was processed during that time. As it was not possible to use all of the detector data from the equivalent period as the crash data, a random number generator was used to select an unbiased sample of detectors and days over the analysis period in order to determine what percentage of time the motorway operated in each occupancy range. Weekends and public holiday weekdays were excluded. The average volume (flow rate) of the occupancy range relative to capacity was calculated (that is, the typical flow). These two values were multiplied and normalised so that the sum over all occupancy ranges was 100 per cent to determine the exposure. A Chi Square Goodness of Fit Test was then used to determine whether there was a significant difference in the observed and expected number of crashes. The expected number of crashes was determined by distributing the total number of crashes on each motorway by the percentage of daily traffic processed in each traffic state (that is, the exposure). Each motorway was treated separately.

Results and Discussion

Analysis of crash data over the past decade (2007 to 2016) has shown that there has been an increase of 59% in the number of casualty crashes on Melbourne's urban motorways. In comparison, casualty crashes on other urban roads have only increased by 1.4% over this period (refer to Table 1). Whilst overall serious casualty crash numbers have decreased on metropolitan Melbourne roads between 2010 and 2016, there has been an increase of 22 per cent in the number of serious casualty crashes on metropolitan Melbourne motorways in this period (refer to Table 2).

Over the past 10 years, traffic (as measured by vehicle kilometres travelled) on the urban motorway network has increased by nearly 50 per cent (VicRoads, 2018). Whilst the measured crash rate on urban motorways is relatively low compared to other urban arterial roads, the high utilisation of motorways means that the total number of casualty crashes occurring on motorways is becoming a significant problem and is rising against the urban trend.

The increasing volumes on urban motorways result in complex traffic situations, including multiple interactions between vehicles. The exposure to risk is growing and that can contribute to higher crash numbers as well as growing congestion. Motorways are operating with peak spread and in heavy conditions over extended periods of the day. Increasing evidence exists that the continual changes required by drivers resulting from the dynamics of traffic flow contributes to the increasing number of crashes.

The overall weekday casualty crash occurrence broadly follows the distribution of traffic over the day, with the highest number of crashes occurring where the traffic volume was highest (refer to Figures 3 and 4). Figure 3 shows the distribution of the weekday casualty crashes by

Table 1. Metropolitan Melbourne casualty crash trends – motorways (main carriageway) versus other urban roads (arterial and local), 2007 to 2016 (Source: VicRoads Road Crash Information System)

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Urban Motorways	441	501	541	523	587	601	581	611	682	699
Other urban roads	9263	9622	9229	9120	9254	9268	9302	9596	9650	9394

Table 2. Metropolitan Melbourne serious casualty crash trends – motorways (main carriageway) versus other urban roads (arterial and local), 2010 to 2016 (Source: VicRoads Road Crash Information System)

	2010	2011	2012	2013	2014	2015	2016
Urban Motorways	164	196	167	190	186	193	200
Other urban roads	2949	2949	2881	2977	2864	2699	2645

crash severity and time of day. For comparison, Figure 4 shows the typical distribution of traffic on the M1 corridor over a typical weekday. It should be noted that the M1 corridor consists of three motorways, namely the Princes Freeway, West Gate Freeway and the Monash Freeway and is a good representation of traffic flow distribution over the day on the entire metropolitan Melbourne motorway network.

Managed Versus Unmanaged Motorways

A comparison of crash rates for a number of metropolitan Melbourne motorways is shown in Figure 5. The Monash Freeway and the Princes Freeway East (shaded green) are managed motorways with an effective coordinated ramp metering system. Casualty crashes are lower on these motorways than on the motorways that are substantially unmanaged. Although some of the other motorways have some coordinated ramp signals, these are less effective both in terms of safety and productivity as the routes are only partially managed (that is, not all of the entrances are controlled) and there may also be different management influences (including by other road operators) that are outside of VicRoads control.

A before and after study was carried out by VicRoads on the Monash Freeway following its upgrade to a 'Managed Motorway' controlled with coordinated ramp metering signals (Gaffney et al., 2017). The initial upgrade included partial management of the mainline with some significant ramps not controlled, resulting in some flow breakdown at bottlenecks. VicRoads has now improved overall control and management of the route (that is, all ramps are now controlled, the algorithm was refined and improved operational strategies were developed) to address learnings from the initial 'Managed Motorway' project.

Figure 3. Weekday casualty crashes on metropolitan Melbourne motorways (main carriageway, 2-directional) by crash severity and time of day, 2012 to 2016

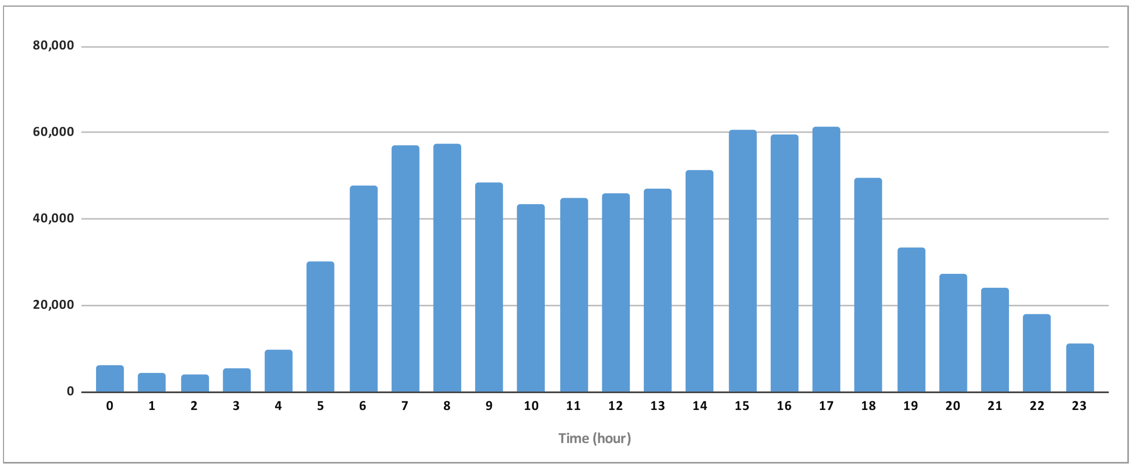

Figure 4. Vehicle trips along the M1 corridor, hourly entering volumes, Wednesday 10th February 2016 (daily count: 852,200 vehicles)

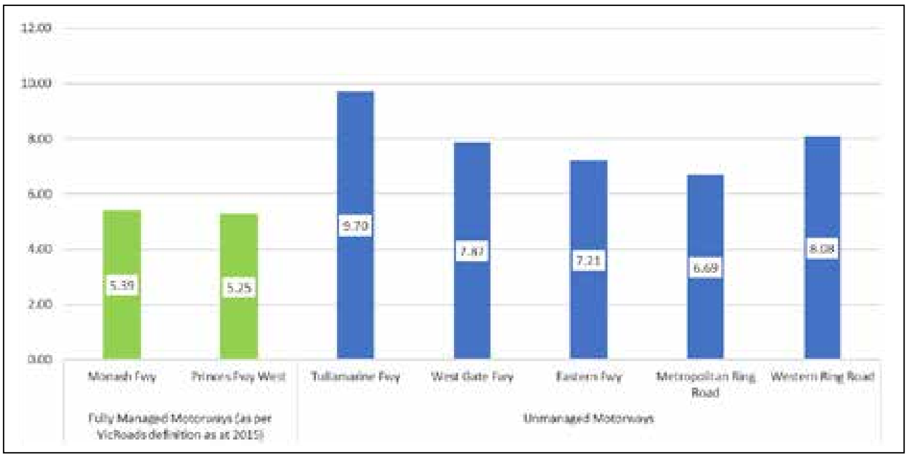

Figure 5. Comparison of casualty crash rates (per 100 million VKT) for selected metropolitan Melbourne motorways, 2012 to 2016

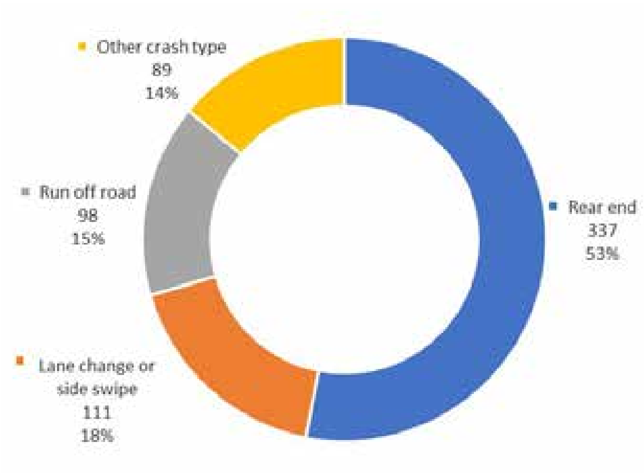

Figure 6. Predominant crash types on metropolitan Melbourne motorways (main carriageway, 2-directional), 2012 to 2016 annual average

Over the 25.5 km length of the freeway, from Toorak Road to South Gippsland Highway and including 14 interchanges, both congestion decreased and safety improved in the five-year period after the upgrade compared to the five-year period before the upgrade despite only partial management of the motorway and despite an increase in lane flows above pre-project conditions. The improved safety outcomes included reduced crash numbers, reduced crash rates and reduced crash severity and were considered to be mainly due to the managed motorway operations with coordinated ramp metering signals which maintained smoother traffic flow, minimising flow breakdown and congestion and reducing speed variations. The latter was achieved through real-time management of mainline occupancy (as a proxy for density) to keep it at an optimal level and avoid triggering congestion (stop-start conditions) which leads to shock wave formation with stationary and slower moving vehicle clusters.

Crash Types

The majority (79%) of casualty crashes on metropolitan Melbourne motorways involve vehicles colliding with other vehicles and not vehicles colliding with fixed objects (infrastructure) which only accounts for 13 per cent of the casualty crashes. The remaining eight per cent include

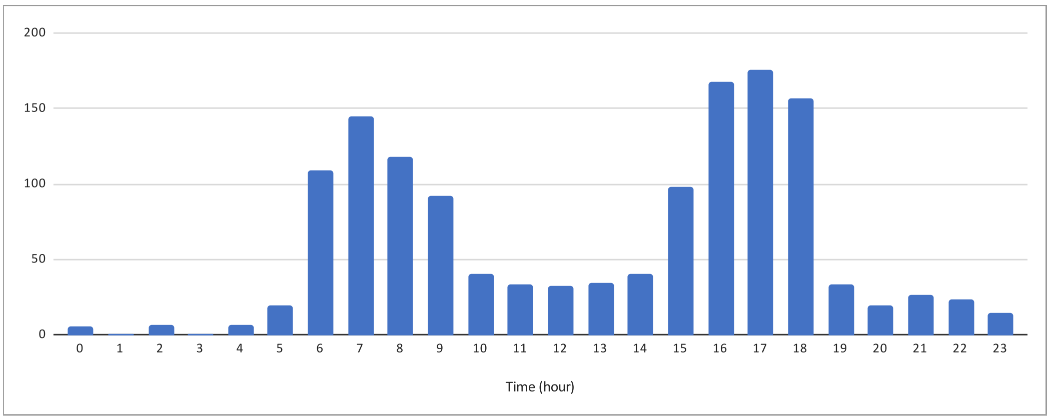

Figure 7. Weekday rear end casualty crashes on metropolitan Melbourne motorways (main carriageway, 2-directional) by time of day, 2012 to 2016

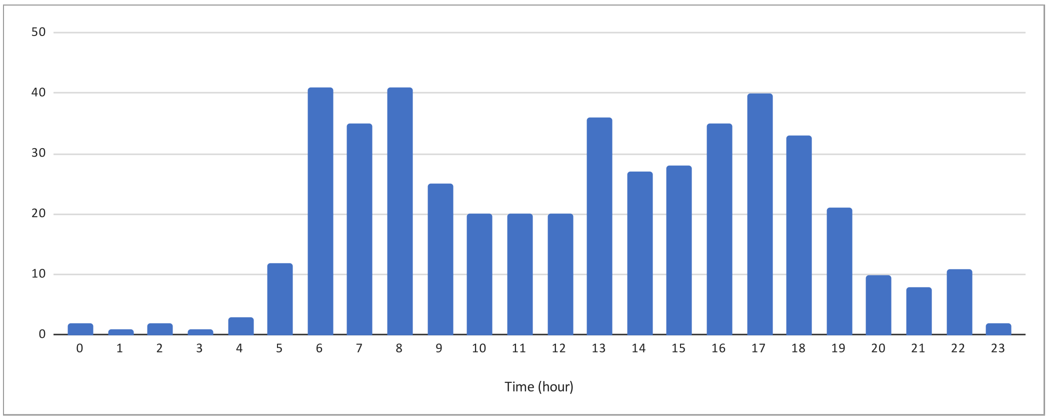

Figure 8. Weekday lane change or side swipe casualty crashes on metropolitan Melbourne motorways (main carriageway, 2-directional) by time of day, 2012 to 2016

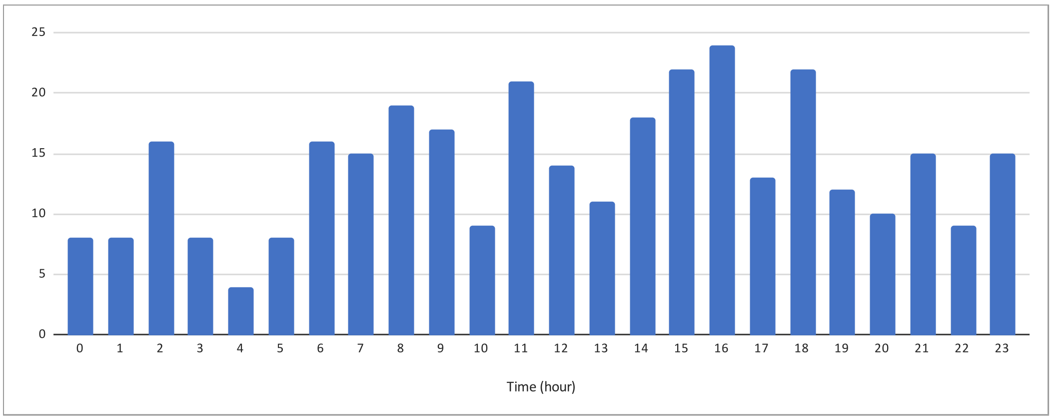

Figure 9. Weekday run off road casualty crashes on metropolitan Melbourne motorways (main carriageway, 2-directional) by time of day, 2012 to 2016

vehicles overturning or losing control (for example a motorcyclist falling of their bike), and collisions with non-fixed objects; animals or pedestrians. The predominant crash types are rear end crashes (53%), lane change or side swipe crashes (18%) and run off road crashes (15%). Collectively these three crash types represent 86 per cent of all casualty crashes on metropolitan Melbourne motorways (refer to Figure 6).

Rear end crashes

The distribution of the metropolitan Melbourne motorway crashes varies by crash type and by time of day. Rear end crashes increase with higher traffic volumes (refer to Figure 7). This may be due to a higher exposure to risk resulting from higher volumes and / or greater levels of congestion. Factors mentioned in the Police reports for rear end crashes include failing to stop due to congestion and/or heavy traffic. The number of rear end crashes in the PM peak period is higher and this may be due to commuters being more fatigued or less focussed on the driving task (Kononov et al., 2012). The introduction of Advanced Driver Assistance Systems, such as Automated Emergency Braking (AEB), could be accelerated to tackle rear end crashes and improve motorway safety.

Lane change and side swipe crashes

Lane-change and side-swipe crashes also increase with higher traffic volumes (refer to Figure 8). This may be due to a higher exposure risk resulting from higher volumes and/or congestion, or where motorists may be avoiding a rear-end crash. There may also be difficulties for motorists finding a gap in heavy traffic for lane changing manoeuvres. Factors mentioned in the Police reports for lane change and side swipe crashes include failing to see the vehicle, blind spots and heavy traffic. Heavy vehicles and motorcycles are involved in many of the lane change and side swipe crashes. The introduction of Advanced Driver Assistance Systems, such as Blind Spot Warning, could be accelerated to tackle lane change and side swipe crashes and improve motorway safety.

Run off road crashes

Run off road crashes generally occur throughout the whole day (refer to Figure 9). Although it is often thought that these crashes occur in light traffic conditions, for example at night due to fatigue and/or alcohol or drug impaired driving, the data indicates that they are also occurring at other times such as in peak hours and in the peak shoulders.

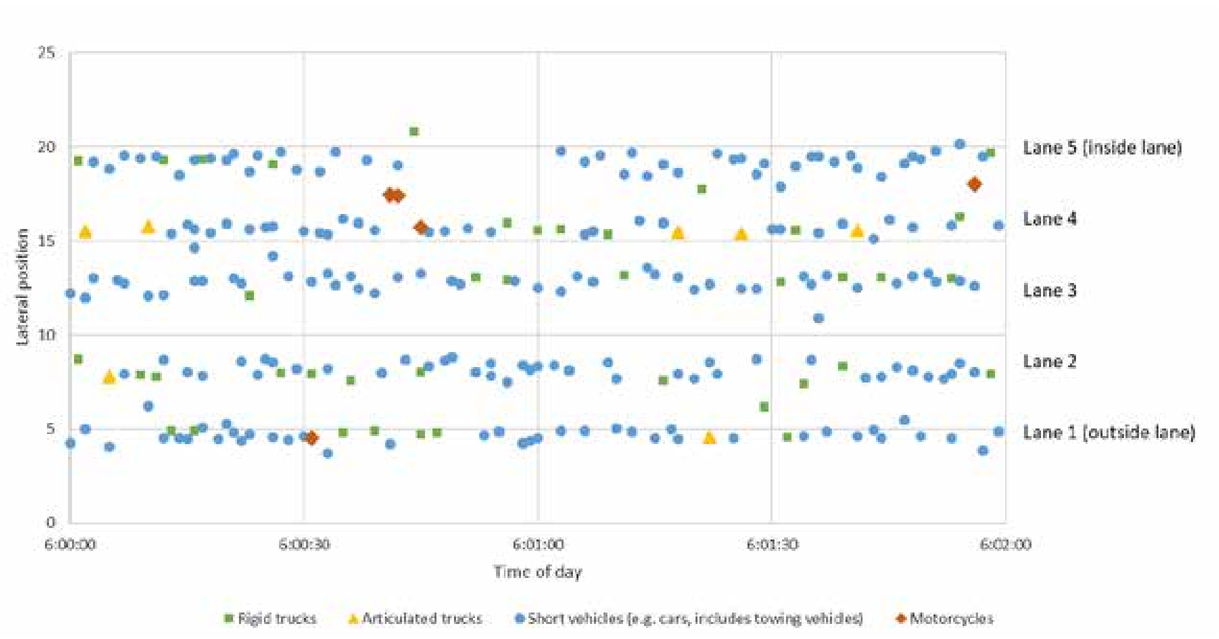

Figure 10. Lateral position (in metres) of different vehicle types on the Monash Freeway between Stud Road and Eastlink (inbound carriageway) between 6:00am and 6:02am on 4 March 2019 as measured by infrared data loggers

Factors mentioned in the Police reports for the run off road crashes include losing control whilst trying to avoid a rear end or lane change collision, losing control when merging, changing lanes or overtaking, losing control when negotiating a curve or bend (especially on a wet road), excessive speed, medical conditions and fatigue.

Vehicle Types

Heavy vehicles, utilities and motorcycles are overrepresented when comparing their involvement in casualty crashes to their share in vehicle kilometres travelled (VKT) on metropolitan Melbourne motorways. Collectively these vehicle types were involved in 43 per cent of all casualty crashes on metropolitan Melbourne motorways.

- Heavy vehicles were involved in 17 per cent of the casualty crashes but only have a 10 to 12 per cent share in all VKT on motorways. Due to their physical characteristics and weight, heavy vehicles are at particular risk of being involved in more severe crashes and were involved in 30 per cent of the fatal metropolitan motorway crashes. Heavy vehicles have issues with blind spots and were involved in 49 per cent of the weekday lane change or side swipe crashes.
- Utilities were involved in 19 per cent of the casualty crashes but have an estimated 10 to 14 per cent share in all VKT on motorways. They were involved in 25 per cent of the fatal crashes and in 25 per cent of the weekday rear end crashes.
- Motorcycles were involved in 11 per cent of the casualty crashes but have a one to two per cent share in all VKT on motorways. Due to their vulnerability, they too are at a higher risk of being involved in more severe crashes and were involved in 23 per cent of the fatal crashes. Motorcycles were involved in 20 per cent of the weekday loss of control (including run off road) crashes and in 18 per cent of the weekday lane change or side swipe crashes.

Recently installed infrared data loggers on the Monash Freeway which can measure speed, volume, occupancy and lateral position of vehicles in real time have shown that some motorcycles are lane splitting in a high-speed environment. Figure 10 shows the lateral position of vehicles on a five-lane section of the Monash Freeway, with the measurement taken from the outside of the carriageway. Motorcycles are symbolised with a brown diamond and can be seen travelling between Lane 4 and Lane 5 (that is, the lanes closest to the median). The output from the data loggers has also shown that some motorcycles travel at extremely high speeds, particularly at night time. For example, over the one-month period, from 20 February 2017 to 20 March 2017, around 180 motorcycles travelled at speeds between 130 km/h and 205 km/h on the inbound and outbound carriageways of the Monash Freeway near Stanley Street. This can pose a significant safety risk not only to the motorcyclists themselves as the motorway is not designed for travel at such speeds, but it also poses a significant threat to slower surrounding vehicles. The current speed enforcement regime is not effective in these cases and a speed enforcement regime using point-to-point cameras integrated with real-time traffic and flow management such as Dynamic Variable Speed Limits would be more effective.

Crashes and Traffic State: Monash Freeway and Eastern Freeway

The results of the analysis of the linked crash and occupancy data on the Monash and Eastern Freeways is shown in Tables 3 and 4 and in Figures 11 and 12. The tables show the number of observed and expected casualty crashes that fall within each of the five categories, where the expected casualty crashes are based on the exposure. The figures

Table 3. Monash Freeway inbound casualty crashes by occupancy class based on 'Traffic States', observed versus expected (based on traffic exposure), 2013 to 2016

	Free flow (0.0 to 4.9% bin)	**Transition (5.0 to 9.9% bin)**	**FBR significant (10.0 to 14.9% bin)**	**FBR relatively certain (15.0 to 19.9% bin)**	**Flow breakdown (20% plus bin)**	**Total**
Casualty crashes (observed)	13	32	34	20	44	143
Daily traffic processed (%)	13.7	28.6	29.1	9.6	19.0	100
Casualty crashes (expected)	20	41	42	14	27	143
Observed versus expected	-7	-9	-8	+6	+17	-

Table 4. Eastern Freeway inbound casualty crashes by occupancy class based on 'Traffic States', observed versus expected (based on traffic exposure), 2013 to 2016

	Free flow (0.0 to 4.9% bin)	Transition (5.0 to 9.9% bin)	FBR significant (10.0 to 14.9% bin)	FBR relatively certain (15.0 to 19.9% bin)	Flow breakdown (20% plus bin)	Total
Casualty crashes (observed)	8	21	16	10	20	75
Daily traffic processed (%)	16.0	37.8	23.9	9.3	13.0	100
Casualty crashes (expected)	12	28	18	7	10	75
Observed versus expected	-4	-7	-2	+3	+10	-

show the percentage of crashes by crash severity that fall within each of the five categories and a comparison with exposure and average travel speed on the Monash Freeway and Eastern Freeway respectively. From these tables and figures, it can be seen that on both the Monash Freeway and Eastern Freeway the crash numbers are lower than the exposure level for all occupancy bins where the breakdown risk is still relatively low (that is, <= 1% per 15-minute interval) and where it hasn't broken down yet (that is, the first three traffic states). In the higher occupancy ranges (15% and above) however, the crash numbers are exceeding the exposure level. These are the conditions where motorists find it harder to drive as they compete for steadily decreasing spare road space and/or where unexpected traffic conditions arise. In the traffic state corresponding to flow breakdown (occupancy of 20% and above) crash numbers are much higher relative to exposure.

Applying the Chi-Square Goodness of Fit Test to the data in Table3 and Table 4 has shown that there was a statistically significant difference for both freeways between the observed and expected number of crashes, where the expected number of crashes is based on exposure values. For the Monash Freeway, Chi-Square ($df = 4$, $n = 143$) = 18.66, $p = .001$. For the Eastern Freeway, Chi-Square ($df = 4$, $n = 75$) = 15.65, $p = .004$. This indicated that there was a statistically significant association between traffic state and the number of crashes.

As quoted by (Kononov, Lyon & Allery, 2011, p. 11), "Accidents on an urban freeway are a by-product of traffic flow. It is reasonable, therefore, to expect that the observation of changes in the flow parameters may give clues about the probability of accident occurrence and changes in accident frequency." By keeping the motorway operating within certain occupancy levels, it may be possible to reduce the number of crashes and improve safety. Both preliminary analysis and overseas examples indicate that there is likely to be an optimal occupancy range where relatively high flow rates coincide with a low breakdown probability and a low crash rate. A key is determining the optimal occupancy level for the conditions that improves safety as well as efficiency and further analysis is needed to specify this optimal operational state.

Crash types and the traffic state

The analysis has also shown that the highest proportion of rear end crashes occur in the traffic state corresponding to flow breakdown (occupancy of 20% and above) for both motorways whilst the highest proportion of lane change or side swipe crashes occurred in the traffic state where there was a significant risk of flow breakdown (occupancy between 10 and 14.9%) on the Monash Freeway and in the transition traffic state (occupancy between 5 and 9.9%) on the Eastern Freeway. The majority of run off road crashes occurred in the free flow and transition traffic states (occupancy less than or equal to 9.9%). Refer to Figures 13 and 14.

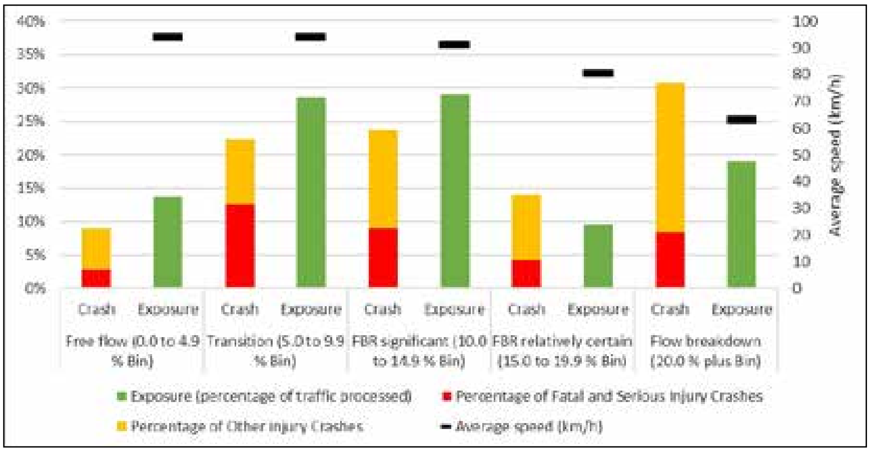

Figure 11. Weekday fatal and serious injury and other injury crashes by occupancy class based on 'Traffic States' with respect to traffic exposure and average speed on the Monash Freeway inbound carriageway, 2013 to 2016

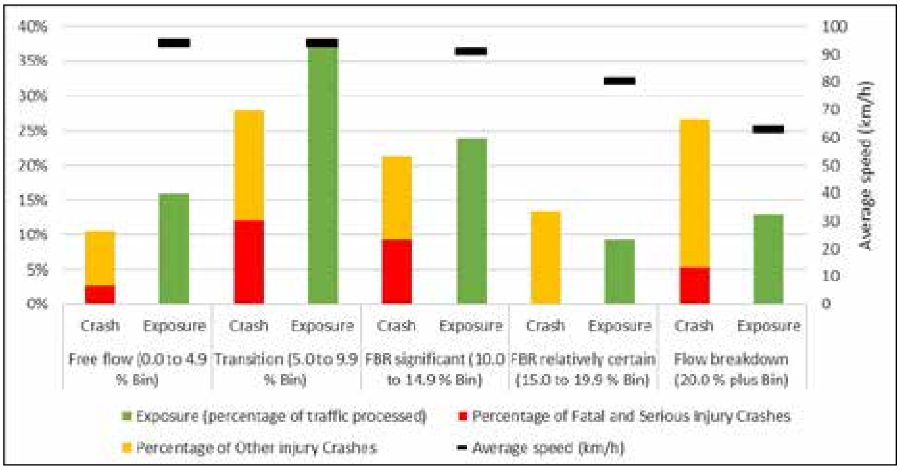

Figure 12. Weekday fatal and serious injury and other injury crashes by occupancy class based on 'Traffic States' with respect to traffic exposure and average speed on the Eastern Freeway inbound carriageway, 2013 to 2016

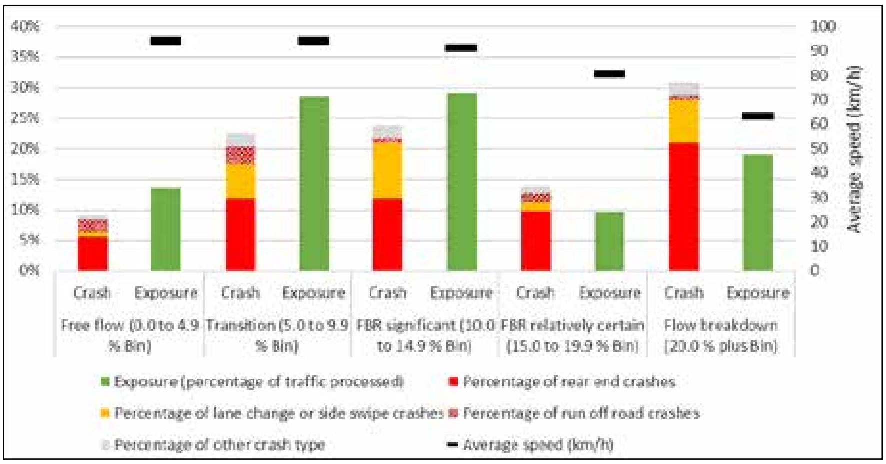

Figure 13. Weekday casualty crashes by crash type and occupancy class based on 'Traffic States' with respect to traffic exposure and average speed on the Monash Freeway inbound carriageway, 2013 to 2016

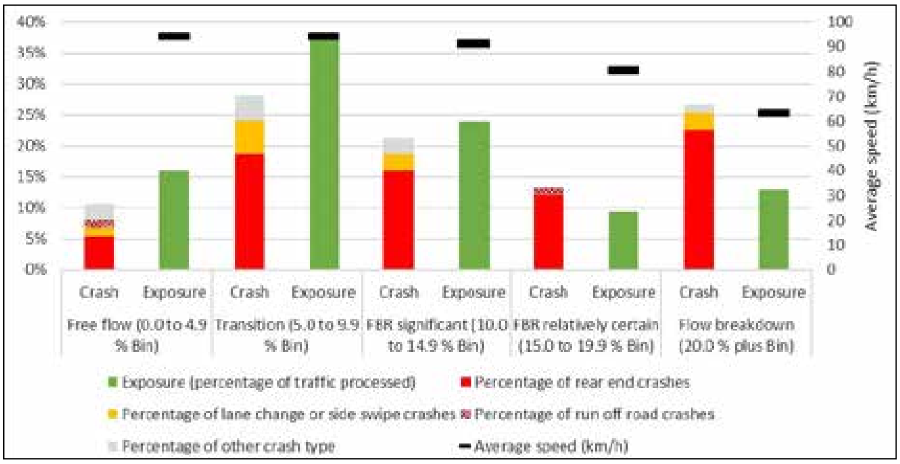

Figure 14. Weekday casualty crashes by crash type and occupancy class based on 'Traffic States' with respect to traffic exposure and average speed on the Eastern Freeway inbound carriageway, 2013 to 2016

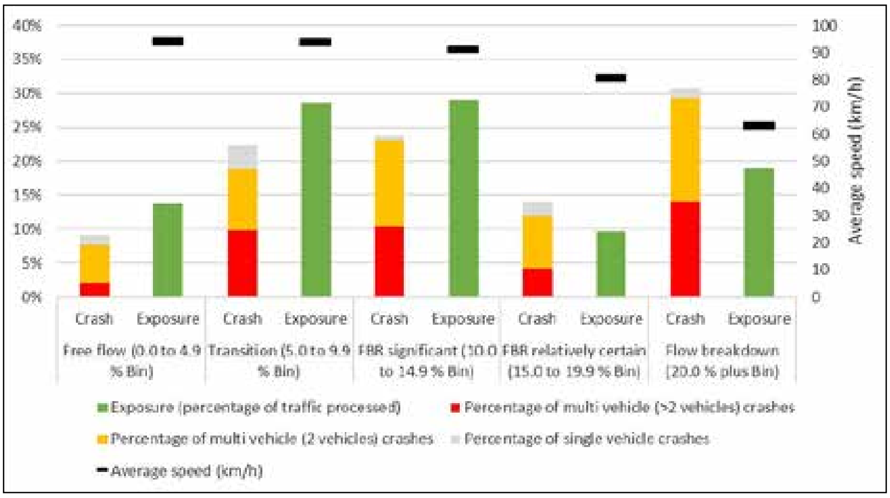

Figure 15. Weekday casualty crashes by number of vehicles and occupancy class based on 'Traffic States' with respect to traffic exposure and average speed on the Monash Freeway inbound carriageway, 2013 to 2016

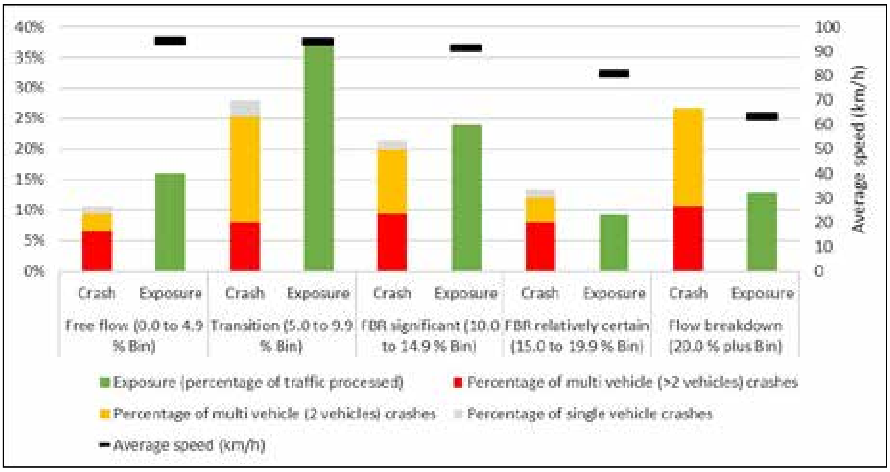

Figure 16. Weekday casualty crashes by number of vehicles and occupancy class based on 'Traffic States' with respect to traffic exposure and average speed on the Eastern Freeway inbound carriageway, 2013 to 2016

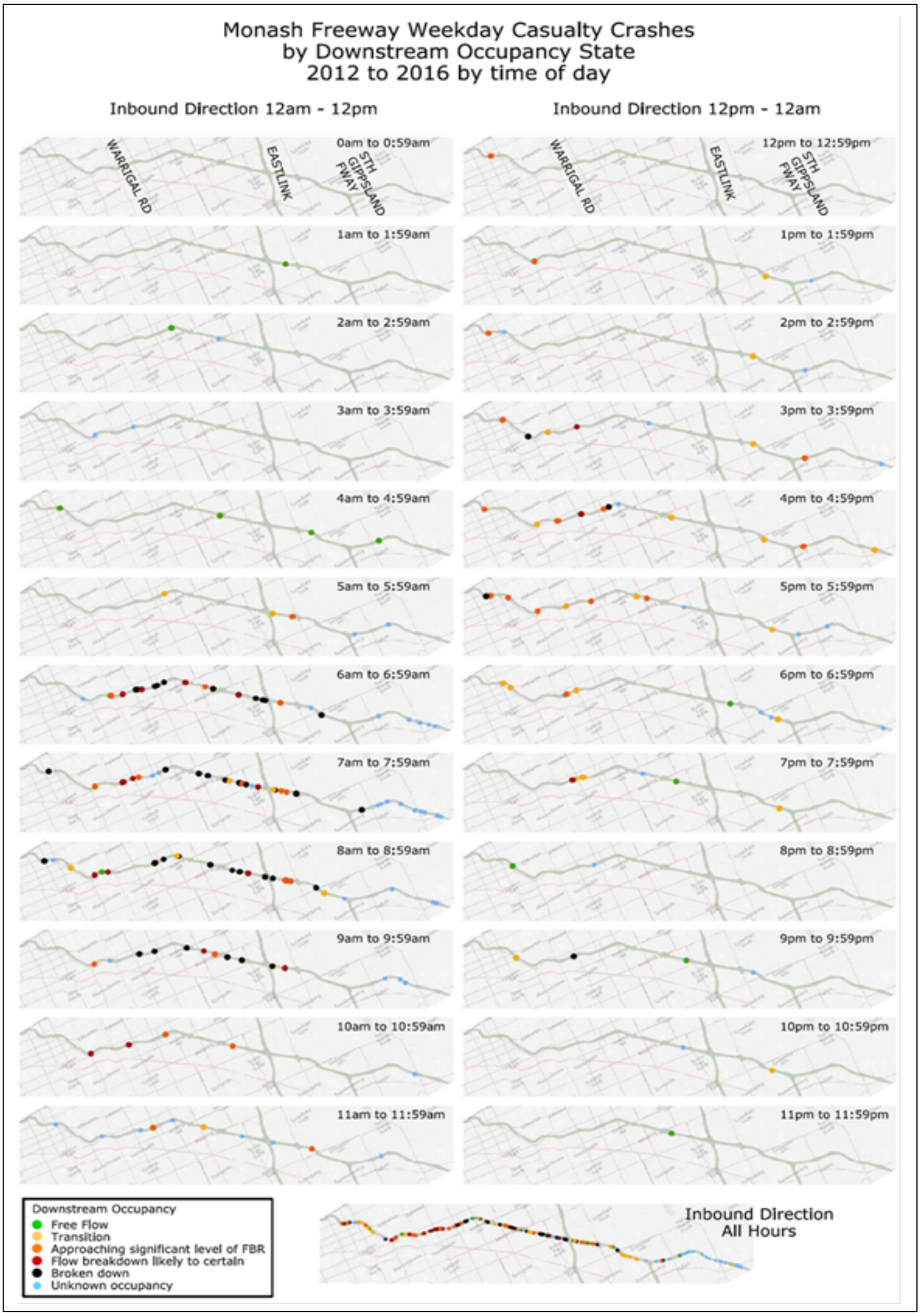

Figure 17. Inbound weekday crashes on the Monash Freeway classified into 'Traffic States' based on closest downstream detector and with respect to hour of day, 2012 to 2016

Number of vehicles and the traffic state

Another result from the analysis of the linked crash and occupancy data was that 95% of the crashes in the highest occupancy bin on the Monash Freeway and all of the crashes in the highest occupancy bin on the Eastern Freeway were multi-vehicle crashes (refer to Figures 15 and 16). Findings such as this broadly align with (Hauer & Kononov, 2018) where multi-vehicle crashes appear to be associated with increasing vehicle concentration.

Spatial and temporal aspects of motorway crashes

To examine the spatial and temporal aspects of motorway crashes, inbound weekday casualty crashes on the Monash Freeway were plotted on a map for each hour of the day and categorised into the five traffic states, plus unknown (refer to Figure 17). Very few crashes occur in free flow conditions (shown as green dots). The highest number of crashes occur in heavier traffic conditions such as where flow breakdown is relatively certain (shown as brown dots) and where flow has broken down (shown as black dots) and these conditions generally align with the peak periods.

Conclusions

Although urban motorways have traditionally been perceived as safe due to low crash rates and high standard of infrastructure, the number of casualty crashes on urban motorways has been increasing at a much higher rate than on other urban arterial roads in metropolitan Melbourne. With increasing traffic, there is a growing risk that the motorways will operate in a critical traffic state most of the day-time hours resulting in more crashes unless something is done to address this.

Both overseas research and output from new technologies deployed by VicRoads on some metropolitan Melbourne motorways provide growing evidence that there is a relationship between motorway crashes and traffic conditions. The detailed analysis undertaken on the Monash Freeway and the Eastern Freeway indicates that there is an association between traffic state and the number of crashes, with higher than expected crashes in the traffic states where flow breakdown is relatively certain (15% to 19.9% occupancy) or has occurred (>= 20% occupancy). This supports the hypothesis that the dynamics of the traffic flow, which cause congestion and require complex driver responses, are a significant contributor to casualty crashes on urban motorways. The analysis has also shown that the casualty crash rate on managed motorways is lower than that on unmanaged motorways.

Improved urban motorway safety can be achieved through the development of Intelligent Transport Systems (ITS) strategies that keep the motorway operating at conditions that minimise flow breakdown. This could be achieved by implementing a multi-criteria motorway management operational strategy that maximises both safety and efficiency with the current cooperative ramp metering, including integrated Lane Use Management System (LUMS) and Variable Speed Limit (VSL) signs, to keep the managed motorway operating at an occupancy that ensures low crash risk as well as high flow rates and high productivity. Safety could be further improved with the provision of additional motorway management infrastructure such as real-time localised congestion warnings, delivered via variable message signs (as done in Europe) or in-vehicle displays, in line with appropriate road design standards.

Enforcement measures such as point-to-point speed cameras integrated with real-time traffic control (for example, Dynamic Variable Speed Limits) could be implemented to tackle excessive speeding and acceleration of the introduction of Advanced Driver Assistance Systems would help to target the predominant urban motorway crash types. In particular, Automated Emergency Braking (AEB) would help tackle rear-end crashes and Blind Spot Warning would help tackle lane change and side swipe crashes.

This research provides the evidence-base for the relationship between urban motorway crashes and the traffic state. Further analyses need to be undertaken, including the determination of the optimal occupancy level that keeps the motorway operating in conditions that prevent flow breakdown, and that maximises both safety and efficiency.

Acknowledgements

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Towards linking driving complexity to crash risk

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Key Findings

- On highly trafficked urban motorways, complexity caused by unstable or congested flow in dense traffic increases the likelihood of human error when performing manoeuvres (e.g. lane changes);
- Complexity characterized by high vehicle density can be avoided through appropriate planning and real-time traffic control;
- Modern infrastructure or vehicle-based technologies allow analysis of individual vehicle manoeuvres e.g. 'Brake', 'Speed alert' or 'Lane change' events in terms of number, spatial or temporal occurrence and risk profiles;
- Emerging technologies show promise in exploring what makes high density traffic complex;

Abstract

The purpose of this article is to present insights into the relationship between complex traffic flow phenomena on urban motorways and crash risk. Unstable or congested flow can trigger low speed/high density clusters (e.g. nucleations or shockwaves) creating 'surprise elements', therefore sharply increasing the cognitive workload for motorists. When combined with reduced road space and freedom to perform needed manoeuvres (e.g. lane changes), conditions can exceed the physical or mental capability and hence increase the likelihood of human error. There is overwhelming evidence that high traffic density drastically increases the crash risk. Some density concentrations can be avoided through appropriate planning and real-time traffic control, resulting in a reduction in crashes. Modern measurement devices allow for the analysis of individual vehicle behaviours such as 'Brake', 'Speed alert' or 'Lane change' events and show promise in providing robust data to further exploring what makes dense traffic complex. This allows establishing relationships between "events as elementary units of exposure" and crash occurrence resulting in a new way of understanding crash rates. These relationships are important to predict crashes, identify high-risk locations, and establish suitable measures for crash reduction.

Keywords

Complexity, Crash risk, Events of Exposure, Lane changes, Traffic management, Urban motorways

Glossary

Bottleneck. A fixed location where the capacity is lower than the upstream capacity.

Capacity. The maximum sustainable flow rate at which vehicles reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period in a specified direction under prevailing roadway, geometric, traffic, environmental and control conditions.

Density. Number of vehicles per unit length of lane or roadway at a given instant in time (vehicles per kilometre)

Disturbance (perturbation). Spatially and temporally confined interruption of homogeneous traffic flow characteristics which can be caused by individual vehicle manoeuvres or vehicle groups (e.g. inappropriate lane changing or abrupt braking) and which can cause larger scale inhomogeneities (e.g. oscillations or nuclei).

Downstream. In the direction of the movement of traffic

Event of exposure. Any event that generates an opportunity for an accident to occur

Flow breakdown. The condition where free-flowing traffic experiences a significant and sudden reduction in speed (for a certain minimum time), with a sustained loss of traffic flow (throughput). This may result in queuing upstream of the bottleneck.

Flow rate (also throughput / volume). The number of vehicles passing a given point on a lane, carriageway or road per unit of time, typically expressed in vehicles per second or an equivalent number of vehicles per hour.

Managed motorway. Motorways managed with coordinated ramp metering signals such as the VicRoads City-Wide Coordinated

Ramp Metering System (CWCRM). May also include management with other tools.

Nucleation. A rapid change in traffic condition when a disturbance (e.g. a slow-moving vehicle impacting other faster moving vehicles) suddenly induces some chaos into the traffic flow which can be a precursor to flow breakdown.

Occupancy. Proportion of the time a length of roadway or traffic lane is covered by vehicles, usually expressed as a percentage sometimes used in operations as a surrogate for density.

Productivity. Mathematical product of flow rate and speed.

Safety drop. A reduction in safety caused by flow breakdown which is defined as the condition where free-flowing traffic experiences significant and sudden reduction in speed (for a certain minimum time), with a sustained loss of traffic flow (throughput). This may result in queuing upstream of the bottleneck.

Shockwave. Shockwaves are defined as boundary conditions in the time-space domain that demark a discontinuity in the flow density conditions.

Upstream. In the direction opposite to the movement of traffic

Introduction

The purpose of this article is to present insights into the relationship between complex traffic flow phenomena on urban motorways and an increased crash risk. This is primarily based on a review of existing work and supplemented by own new data as continuously measured through state-of-the-art detection and observations through permanent camera installations across the metropolitan Melbourne motorway network. It is intended that these insights inform potential future directions.

There is overwhelming evidence that high vehicle density (i.e. a great number of vehicles per kilometre) drastically increases the crash risk (macro level). What is less clear are the microscopic (i.e. individual vehicle related) mechanisms that cause safety issues. Influencing these mechanisms requires deep understanding based on a robust analysis.

Complex traffic flow phenomena include unstable or congested traffic flow, triggering nucleations and shockwaves (refer to Kerner, 2017) that propagate against the direction of travel and increased lane changing activity (refer to VicRoads, 2020). Such conditions usually come as a surprise to motorists and hence can drastically increase the cognitive workload for motorists which, combined with reduced freedom to perform needed manoeuvres (e.g. thousands of lane changes per hour and kilometre to fill all lanes to capacity), create potentially hazardous situations.

mproving road traffic safety and efficiency on highly saturated urban motorways and high-volume arterial roads requires an understanding of the complex traffic phenomena and the mechanisms that can trigger them. For example, as motorways approach capacity, there is an increasing number of interactions between individual vehicles that cause traffic to slow down, longitudinal oscillating waves to form, and lane change numbers to rise. It appears that the overwhelming share of urban motorway crashes are linked to critical traffic flow conditions and most of them are multi-vehicle crashes (refer to Hovenden et al., 2020).

Along with a heterogeneous vehicle fleet comes an even more diverse driver population expressing numerous behaviours which influences interactions between vehicles and ultimately determines the overall traffic performance outcome of a system (refer to Gaffney, 2017 and Zhuk et al., 2017). Human behaviours include unique personal (instantaneous) choices of:

- Speed;
- Travel lane;
- When and where to change lanes;
- When to enter and/or leave the motorway; and
- Gear changing, mirror glancing, braking and acceleration actions to maintain their position within the traffic stream.

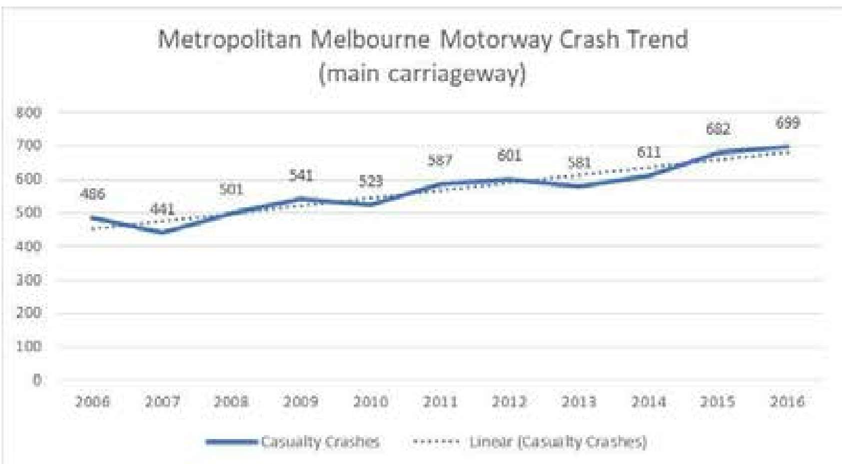


Figure 1. Growth in Metropolitan Melbourne motorway casualty crashes (Source: VicRoads Road Crash Information System)

The Metropolitan Melbourne motorway network carries 40% of the urban arterial road travel as measured in Vehicle Kilometres Travelled (VKT), with an upward trend (VicRoads, 2018). Crashes on this network comprise around 15% of urban Fatal and Serious Injury (FSI) crashes. Urban motorways are therefore generally showing good safety performance. However, as motorways are partially taking over the role of other, congested arterial roads (i.e. accommodating more short trips), there is a disproportionate increase in VKT travelled on them and they are operated at or close to capacity (approaching congestion) more of the time when the highest number of vehicle conflicts occurs. For these two reasons, the absolute number of FSI crashes on urban motorways is increasing (refer to Hovenden et al., 2020) and there is a very pronounced rise in casualty crashes (refer to Figure 1).

The intent of this article is to firstly gain interest and awareness as well as stimulate thinking in this relatively new research area, and secondly present ideas on how to mitigate complex traffic flow phenomena and corresponding risks. Thirdly, it aims to encourage thinking about how to expand the presented insights and ideas to non-motorway roads.

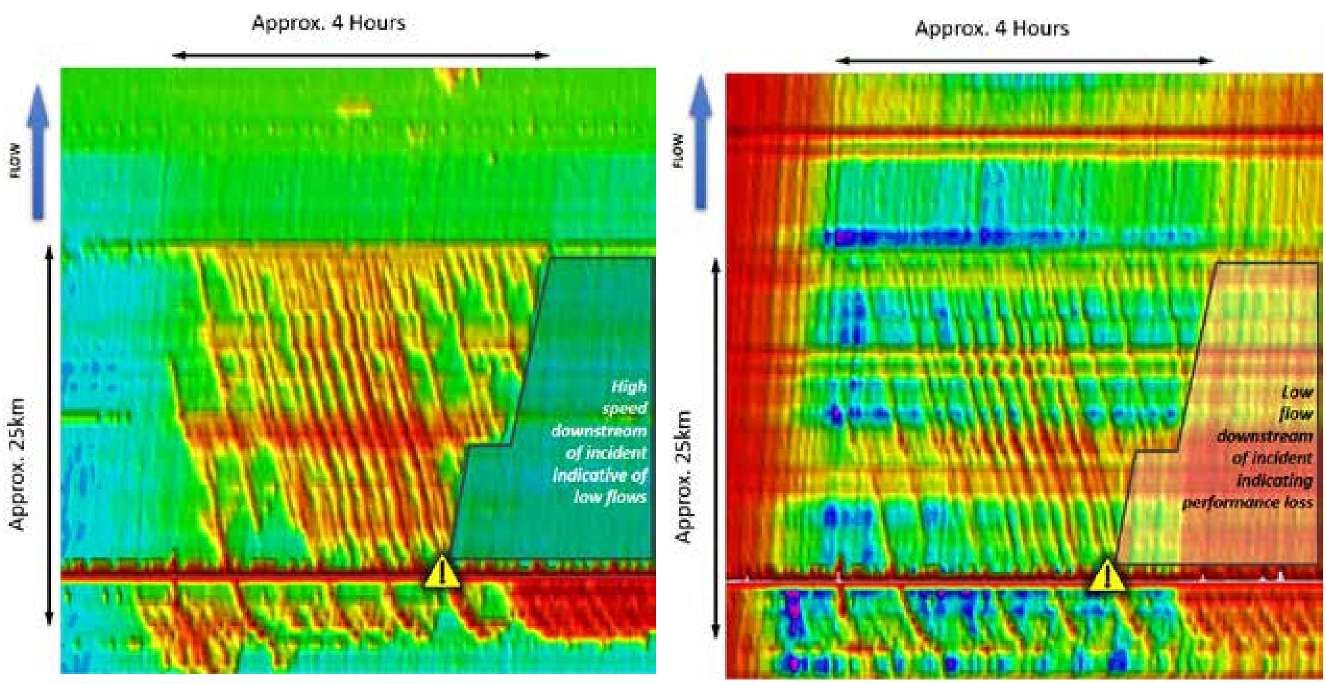
The authors think that the globally rising trend in urban motorway crash occurrence requires new thinking compared to the more traditional approaches.

Methods

The authors of this article undertook a comprehensive literature review including conversations with many of the corresponding authors (e.g. refer to Elvik, 2014, Gitelman et al. 2016 and Hovenden et al., 2018) which resulted in the documentation of the overall view from a road operator's perspective.

This literature review was combined with daily traffic studies over many years which demonstrated the traffic flow complexity including many critical driving manoeuvres. This comprised ongoing camera observations, traffic state measurements and data analysis for some urban (managed) motorway corridors.

VicRoads guidelines require full coverage of their managed motorway network with cameras so that hundreds of CCTV cameras were available for such studies. Also, VicRoads as part of its role as road planner, designer and operator over recent years introduced modern infrastructure-based technologies for the measurement of speed-, volume- and occupancy data needed for real-time traffic control (rather than outdated loop detector technology, discussed under "Measurement" below). These were investigated regarding their potential to gain insights into the consequences of thousands of vehicle manoeuvres and interactions on traffic flow complexity and hence a potential safety risk (based on the measurement of individual vehicle manoeuvres such as 'braking', 'speeding' or 'lane changing', measured in hundreds of locations across the entire metropolitan



Contour Plot for Speed (top) and Corresponding Flow (bottom) per lane

Note: Direction of travel is from bottom to top and the progression of time is from left to right; red colour indicating low speed (left) and flow (right)

Figure 2. Flow breakdown impact on affected length of motorway and duration (Source: VicRoads, 2020)

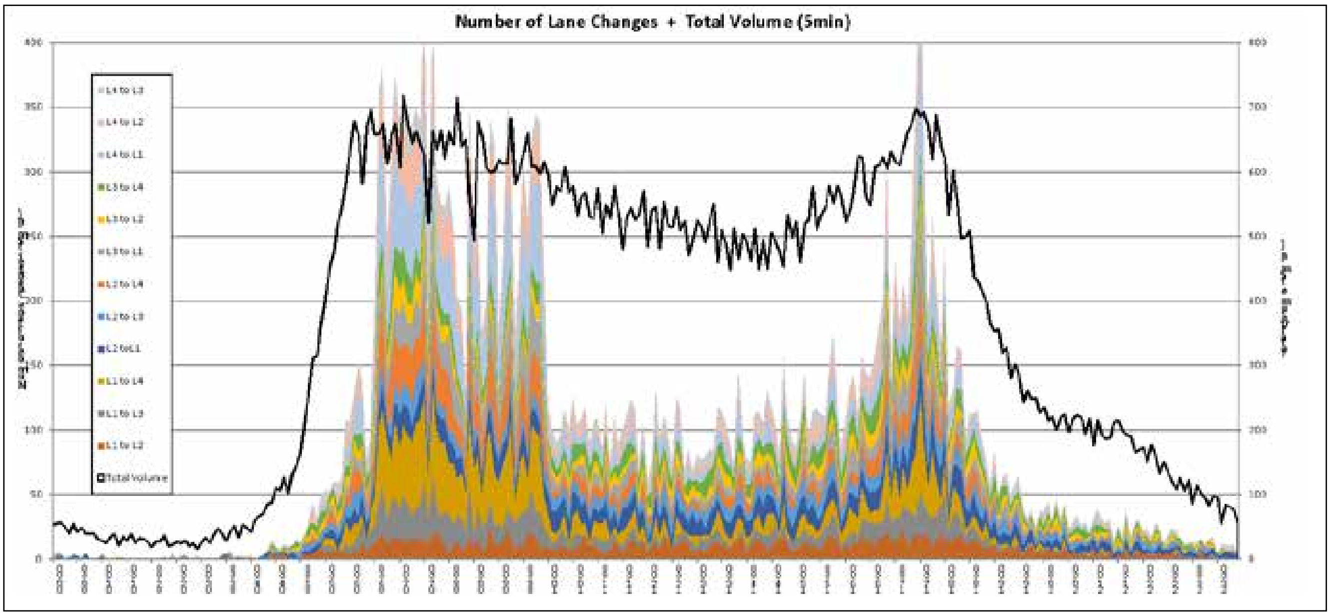


Figure 3. Stacked histogram showing the individual lane movement between L1 (outer lane) and L4 (median lane) plotted with total volume (5 min) (Source: Hall et al., 2018)

Melbourne motorway network). Such insights can then be linked to current and potential future road design and operational practice to mitigate complexity. This resulted in an outlook on practical consequences.

Results

Summary of existing work

Recent studies provide overwhelming evidence that on highly trafficked urban motorways the dynamic of the traffic flow causes transitions to unstable or congested conditions which are characterized by an increased density and hence complexity. This contributes significantly to the increasing number of crashes (refer to Golob et al. (2004), Kononov et al. (2008, p. 37), Kononov et al. (2011) and Hovenden et al. (2018)). These studies do not explore the underlying mechanisms that make dense traffic complex so that appropriate countermeasures can get developed.

Observations

On urban motorways and likely also on other high-volume multi-carriageway roads, unstable or congested traffic regularly results in the generation of shockwaves shown as red, diagonal bands in Figure 2 (refer to Treiber and Kesting, 2013 and Kerner, 2017). Shockwaves propagate upstream against the direction of travel at a speed of around 20 km/h (refer to Austroads, 2009). When the shockwave comes as a surprise, drivers must deaccelerate very quickly. This increases the likelihood of human error when performing needed manoeuvres (e.g. lane changes) and hence the likelihood of crashes. Appropriate planning and real-time traffic control can mitigate some of this complexity characterized by vehicle density or roadway occupancy concentrations (macro level).

A great number of individual vehicle manoeuvres such as 'Brake', 'Speed alert' or 'Lane change' events (micro level) can be measured and processed (e.g. linked to crashes) with modern infrastructure- or vehicle-based technologies (refer to Figure 3). This allows for a robust analysis (i.e. not significantly influenced by randomness).

Hence, such modern technologies show promise in further exploring what makes dense traffic complex and establishing robust relationships between Number of crashes ('Effect') and events as elementary Unit of Exposure ('Cause') - resulting in a 'non-traditional' crash rate. Establishing the relationship between cause and effect is important to identify high-risk locations or operational states, predict crashes, and to establish suitable measures for crash reduction including operational ones. The crash rate is defined as follows (refer to Elvik, 2014):

Crash Rate = Number of Crashes / Unit of Exposure (or 'Exposure') (1)

The crash rate must be determined in a series of trials. Traditionally, Vehicle Kilometres Travelled (VKT) are used as 'Exposure'. However, for the most significant crash types on urban motorways ('rear-end', 'lane changing' – refer to Hovenden et al., 2018), this is unsuitable to predict the number of crashes expected to occur under different conditions. For example, a VKT based crash rate may have been determined on a busy motorway with regular operation close to or above capacity which is linked to many 'rear-end' and 'lane changing' crashes occurring. Applied to another motorway where traffic levels are lower (in relation to capacity), this will lead to an overestimation of the number of such traffic-related crash types. From camera observations, it is the critical driving manoeuvres such as harsh braking (potentially caused by a shockwave) or lane changing into a too narrow gap between two vehicles (or

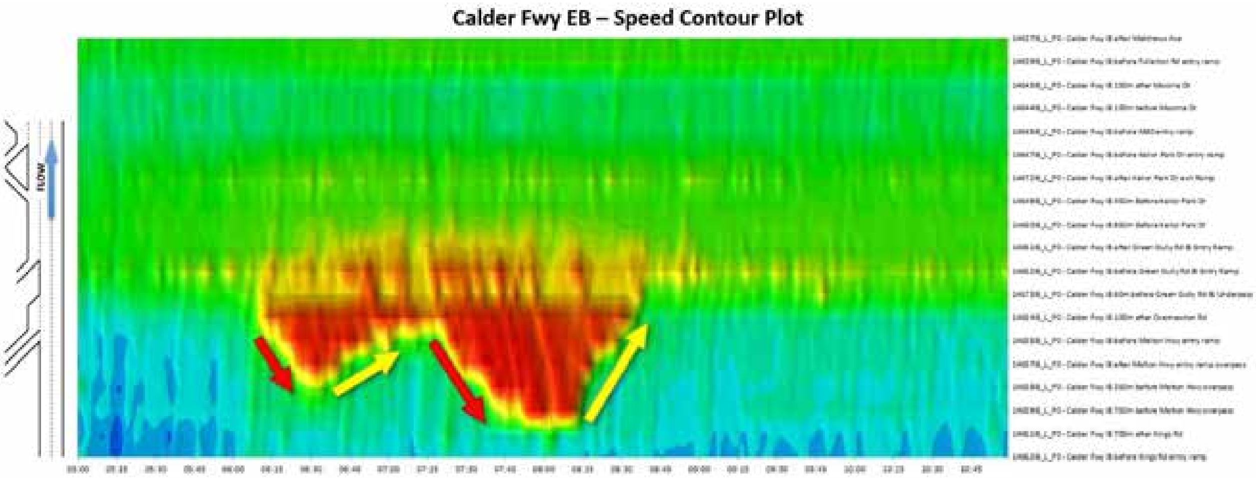


Figure 4. Calder Freeway (unmanaged) – Speed surface contour showing the propagation of the congested area (red) upstream (down the page) (Source: VicRoads, 2020)

their combination) that increases the crash risk. Therefore, it appears more suitable to use such events as 'Exposure'. Events need to be countable (refer to Elvik, 2014) and predictable by models in order to be a useful concept in informing planned changes to conditions.

Traffic complexity in an urban motorway environment

High level description

In Australia and most other industrialised countries, the traffic state on urban motorways is (to varying extents) routinely, permanently and comprehensively measured by in-pavement detectors which in real-time capture the parameters speed, volume (flow rate) and occupancy (that is, the proportion of time a length of roadway or traffic lane is covered by vehicles, usually expressed as a percentage).

As the number of vehicles per kilometre (i.e. density) rises there is an increasing number of interactions between individual vehicles which creates complexity (refer to Section 'Introduction') and a growing risk of flow breakdown (i.e. an abrupt transition to congested conditions characterized by low average speed and high density). Once it has broken down, this creates shockwaves that propagate against the direction of travel (refer to Figure 4). Shockwaves can affect the motorway for many kilometres and for many hours and are characterized by a high differential speed between approaching vehicles and those at the back of the queue and a very high number of vehicle interactions within the jam.

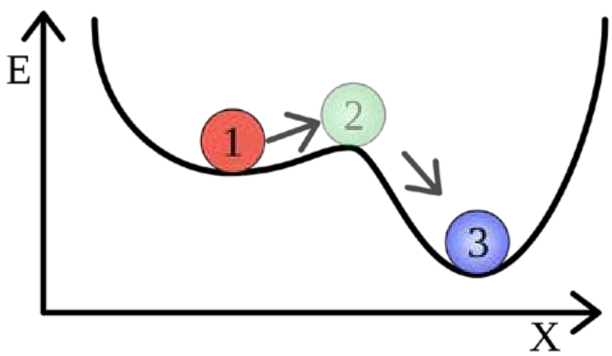


Figure 5. To change from a higher traffic state (expressed as a high value of E) to a lower state (expressed as a low value of E) a small nudge is required (Source: https://en.wikipedia.org/wiki/Metastability)

New insights into the mechanisms that cause unstable flow or congestion, including individual vehicle manoeuvres, are now possible due to advancements in detection technology (refer to Section 'Lane changes as an example of countable events'), which provide richer, finer grained and more accurate data sets. This enables control of numerous compounding and complex motorway phenomena and their triggers, e.g. through improved design limiting lane changes/turbulences /oscillations and an improved City-Wide Coordinated Ramp Metering System (CWCRM) system mitigating flow breakdown and congestion, in turn improving road safety (refer to Gaffney et al., 2017, Appendix A.1 for more detail). Measurement and analysis of lateral movement data (i.e. lane changes) is also suitable to explain many of the phenomena linked to merging, diverging and weaving (e.g. reduced capacity).

The mechanisms of traffic flow breakdown as a transition to congestion

High traffic load at a bottleneck combined with disturbances are the usual 'ingredients to make a traffic jam' (Treiber & Kesting, 2013) or precursors to flow breakdown. A small disturbance is all that is required to transition from a metastable traffic state to a lower traffic state (refer Figure 5).

A micro factor (i.e. individual vehicle manoeuvre) occurring in the presence of other precursor conditions (e.g. a nucleation resulting in a short-term and locally confined density concentration, refer to Kerner, 2017) is typically the actual trigger of a change in the traffic state. An example is a

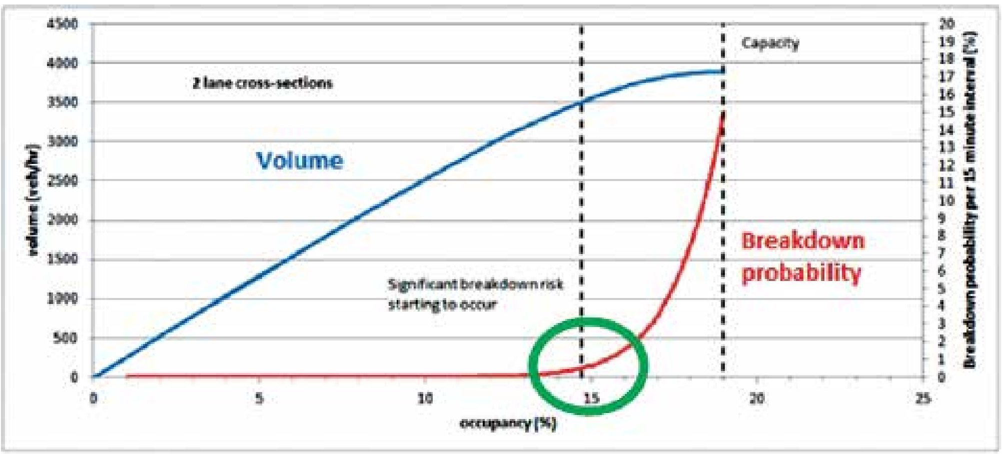


Figure 6. Flow rate ('Volume') and breakdown probability plotted against occupancy (2 lane cross-sections) (Source: VicRoads)

disruptive lane change into a smaller than desirable gap or a **sudden braking** sequence (deacceleration and/or swerving to other lanes).

VicRoads is now able to determine a target operational state where the flow rate is already high, and the flow breakdown risk is still low. This is used for the determination of Maximum Sustainable Flow Rates (MSFR) for roadway planning, design and operation (refer to VicRoads, 2019). The VicRoads CWCRM targets an occupancy value that is equivalent to a flow breakdown risk of 1% over 15 minutes or 10% over 3 hours (refer to Figure 6).

Types of system losses in case of congestion

The following list describes some of the issues resulting from flow breakdown (refer to VicRoads, 2020):

- 'Capacity Drop' or 'Flow Loss' (a major economic loss due to less vehicles being serviced from the infrastructure).
- 'Speed Drop' (a major economic loss due to lower average speed resulting in cumulative hours of delay).
- 'Delay Escalation' (as delay increase is not linear as speed deteriorates, i.e. the economic loss increases exponentially as motorway speeds decay).
- 'Safety Drop' (increased crash risk occurs around the density values associated with flow breakdown) (refer to Hovenden et al., 2020).
- 'Increased Emissions' (from driving in congested and potentially stop-start conditions and from diversions which result in longer trips).
- 'Increased Energy Use' (increased fuel consumption when driving in congested and potentially stop-start conditions and from diversions which result in longer trips).
- 'Decreased Reliability' (when any bottleneck sets in and the travel times increase significantly, the flow and speed outcomes can be very variable).

A key VicRoads objective for motorway operations is 'Don't Let it Break' or 'Keep it Moving'.

Acknowledging the scale of system losses due to congestion

When bottlenecks are activated (i.e. flow breakdown and congestion occurs), they often cause wider system problems, both upstream and downstream, of an active bottleneck (e.g. spreading over 25 kilometres and 4 hours, refer to Figure 2).

Upstream of an active bottleneck, traffic speeds and flows are often significantly reduced due to congestion and shockwaves that form with continual demand arrival. These propagate upstream against the direction of travel. Depending on the traffic flow characteristics, this propagation typically happens at a speed of around 20 km/h (refer to Austroads, 2009) so that if it the shockwave moves around a bend or similar, it can come as a surprise to drivers that they have to deaccelerate very quickly.

Downstream of an active bottleneck, flows are constrained by reduced discharge flows from the bottleneck, resulting in below capacity flows and asset underutilisation.

Also, often diverted traffic is loaded onto the arterial road network that typically has a 4 to 5 times higher crash rate compared to the motorway (refer to VicRoads Crashtraff, 2009 to 2013 data).

Cognitive workload

Human performance capability has limits

It is often stated that the main cause of road crashes is the human factor (i.e. driver´s behaviour). Crash records tend to indicate that more than 90 percent of road accidents have been caused by human error (e.g. refer to ANCAP, 2017). While acknowledged in literature (refer to Cunningham et al., 2017), what is given too little regard in practice is that the human body and mental performance capability has limits (e.g. described by a wide variation of reaction times, refer to Figure 7).

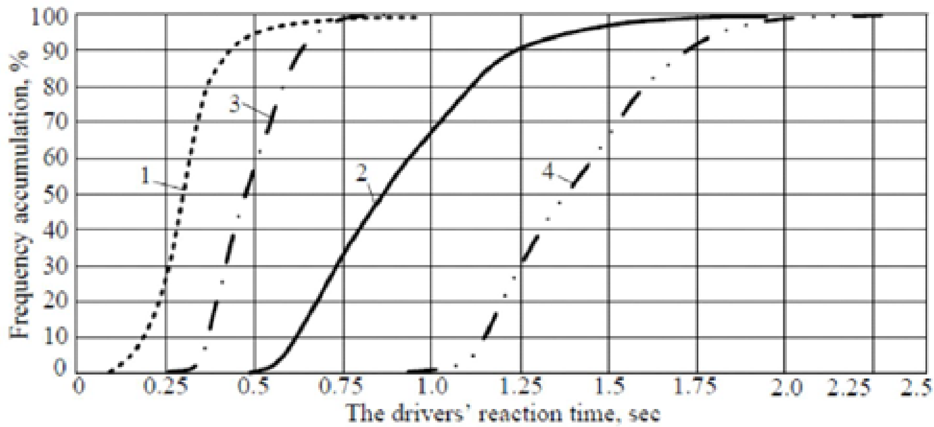


Figure 7. The cumulative curves of the interval distribution in the driver's performance: 1 – the latent time in the laboratory conditions; 2 – the reaction time in the laboratory conditions; 3 – the latent time in the real conditions; 4 – the reaction time in the real conditions (Source: Zhuk et al., 2017)

However, this is highly relevant, given that the trigger for a crash (e.g. a shockwave) usually comes as a surprise event for which the driver does not have an instinctive response or previous experience (refer to Section 'Traffic complexity in an urban motorway environment').

Challenging driving task on complex urban motorways

Drivers can perform certain simple tasks with relative ease with minimal chance of error. Therefore, higher speed driving (with lower traffic densities) on motorways does not necessarily result in proportionally more crashes (i.e. higher crash risk). However, as traffic volumes and densities rise there is an increasing number of vehicle interactions with movements within and between different lanes (i.e. lane changes). Vehicles in the same lane (e.g. fast traffic) are constantly catching up to slower traffic requiring braking followed by acceleration events which are occurring with reduced empty road space, giving rise to more complex driving situations (e.g. more blind spots and lane changing into increasingly smaller gaps as volumes rise). These factors compound the task which requires considerably more skill and precision by the driver and additional collaboration between drivers to perform seemingly normal and simple tasks such as lane changing to gain advantage in the flow, to utilise all of the motorway capacity, or to achieve a desired objective such as repositioning the vehicle into the slow lane for a nearby exit.

More complexity more human error

James Reason (Reason, 1997) presents information regarding the probability of making errors when performing tasks with a given description. Reason's work shows *' familiarity with and the complexity of the task and the estimated error probability for each of them, where the probability of error equals the number of times an error was made divided by the number of times the task was performed'.* In the case of driving on motorways and making most lane changes, drivers are used to familiar (relatively simple) tasks (i.e check mirrors (few blindspots), turn on their indicators and make a lane change into a resonably sized gap), so therefore their error rate is low for the majority of the time. However when traffic volumes rise, headways become smaller and there are many more blindspots. When

Table 1. Probability of making errors when performing certain task - adapted from Reason

Task description	Error probability
Totally unfamiliar, performed at speed with no idea of likely consequence	0.55
Shift or restore system to a new or original state on a single attempt without supervision or procedures	0.26
Complex task requiring high level of comprehension and skill	0.16
Fairly simple task performed rapidly or given scant attention	0.09
Routine, highly practiced, rapid task involving relatively low level of skill	0.02
Restore or shift system to original or new state, following procedures with some checking	0.003
Completely familiar, well designed, highly practiced routine task, oft-repeated and performed by well motivated, highly trained individual with time to correct failures but without significant job aids	0.0004
Respond correctly to system when there is an augmented or automated supervisory system providing accurate interpretation of system state	0.0002

Table adapted from Reason (1997)

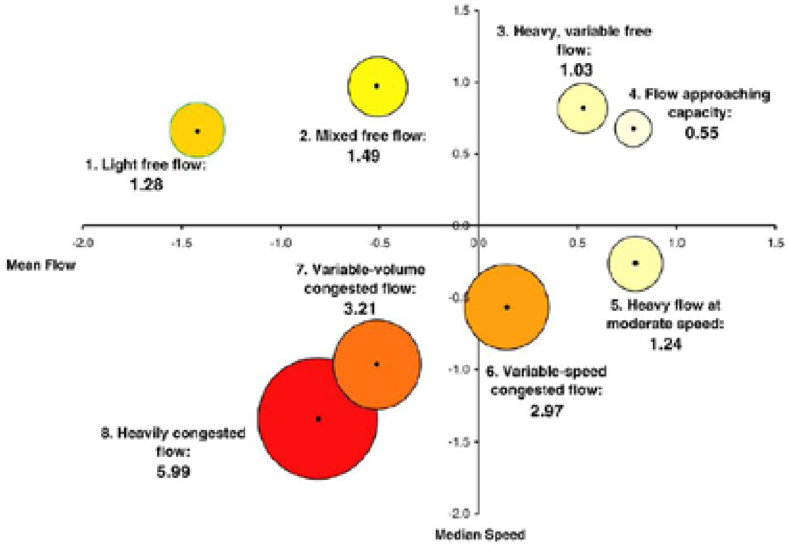


Figure 8. Estimated Crash Rates for different Traffic Flow Regimes, plotted in standardised speed-flow space; intercept of the horizontal and vertical lines represents average speed and flow, negative/positive values along these lines mean below/ above average speed and flow (Source: Golob et al., 2004)

such task coincides with longitudinally moving waves (e.g. shockwaves) which may be apparent to the driver or not, gaps between vehicles can close suddenly in their lane and/ or in adjacent lanes they are manoevering into. Often the driver is not aware of the sudden increase in complexity they need to deal with and consequently, their judgement when suddenly faced with a shockwave arriving just ahead of them as they begin checking their mirrors as they decide to lane change can result in a very dangerous situation. It is under these conditions that many crashes occur (refer to Hovenden et al, 2018). Table 1 shows that with reducing familiarity and as the task increases in complexity the human error rate rises markedly (i.e several orders of magnitude) and hence a dangerous situation can emerge instantaneously and unexpectedly in the traffic flow.

It is obvious that such dangerous situations become even riskier if coinciding with any kind of distraction, whether it is through mobile phone usage or inappropriate roadside advertisements (refer to Gitelman et al., 2010 and Cunningham et al., 2017), potentially exacerbated by inclement weather conditions leading to damp or wet road surfaces and hence longer braking distances.

Studies of the relation between complexity and crashes

There is overwhelming evidence internationally that the dynamic of the traffic flow which through traffic state changes induces an increased complexity contributes significantly to the increasing number of crashes. Golob et al. (2004) have identified the adverse safety effects of congested motorways and state that the crash rate can rise as much as 5-6-fold under 'Heavily congested flow' conditions (refer to Figure 8). Kononov et al. (2008, p. 37) conclude that 'on uncongested segments the number of crashes increases only moderately with increase in traffic; however, once some critical traffic density is reached, the number of crashes begins to increase at a much faster rate with an increase in traffic.' Kononov et al. (2011) in a different article state that 'Accidents on urban freeways are a by-product of traffic flow'.

VicRoads recently undertook a project to test the following hypothesis (refer to Hovenden et al., 2018):

'The dynamic of the traffic flow requires significant changes to driver behaviour (e.g. abrupt braking or lane changing manoeuvres) which in turn contributes significantly to the increasing number of casualty crashes. Providing new tools and technology solutions may prove more beneficial than just traditional approaches to improving hard road infrastructure (civil) provision.'

The project investigated 3,058 casualty crashes that occurred on metropolitan motorways between 2011 and 2015. The source of the crash data was police-reported crashes, accessed through VicRoads Road Crash Information System. The focus was on the number of crashes and killed or injured persons, crash types, vehicle characteristics, and time and location of occurrence. The main findings of this project were as follows:

- Most (79%) of casualty crashes on metropolitan Melbourne motorways involve vehicles colliding with other vehicles and not vehicles colliding with fixed objects (infrastructure) which only accounts for 13% of the casualty crashes. The remaining 8% include vehicles overturning or losing control (for example a motorcyclist falling of their bike), and collisions with non-fixed objects, animals or pedestrians.
- The predominant crash types are rear end crashes (53%), lane change or side swipe crashes (18%) and run off road crashes (15%). Collectively these three crash types represent 86% of all casualty crashes on metropolitan Melbourne motorways.

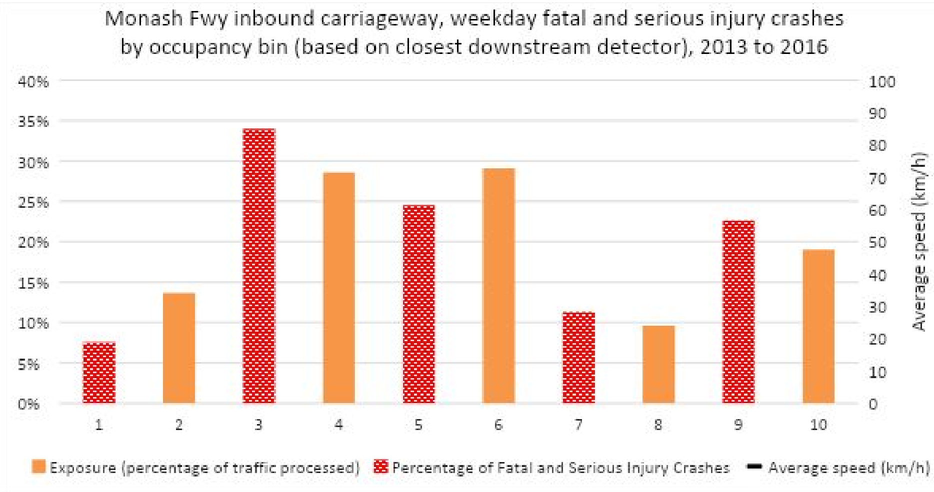


Figure 9. Fatal and serious injury crashes by occupancy class based on 'Traffic States' with respect to traffic exposure and average speed on the Monash Freeway, 2013 to 2016 (Source: VicRoads)

- Heavy vehicles, utilities and motorcycles are overrepresented when comparing their involvement in casualty crashes to their share in vehicle kilometres travelled (VKT) on metropolitan Melbourne motorways. As an example, motorcycles were involved in 11% of the casualty crashes but have a 1-2% share in all VKT on motorways. Due to their vulnerability, they too are at a higher risk of being involved in more severe crashes and they were involved in 23% of the fatal crashes. Notably, state-of-the-art detection technology showed some extremely high motorcycle speeds which indicate inappropriate speed enforcement even on our most important roads.
- Managed motorways in terms of the traditional casualty crash rate are around 30% safer than unmanaged motorways (refer to Section 'Events of exposure' – 'Theory').

Casualty crashes that happened on the Monash Freeway (439 crashes) were investigated in greater detail, including the use of the detailed free-text descriptions and images provided by the Police. Notably, the road infrastructure was not mentioned as a casual factor in any of the descriptions of these crashes by the Police. Instead, mention was made of heavy traffic, congestion, vehicle blind spots. Serious casualty crashes that happened on the Monash Freeway were linked to the traffic state at crash occurrence (inbound and outbound directions). In the higher occupancy ranges (15% and above, i.e. where an increased flow breakdown risk prevailed or where it had already broken down), the crash numbers were significantly exceeding the exposure level (in terms of VKT). Further detail is included in Hovenden et al., 2018.

Additional analysis of the data from the Monash Freeway used by Hovenden et al. showed that the percentage of FSI crashes in all casualty crashes in the higher occupancy ranges (15% and above) was lower (28%) than in the lower occupancy ranges (44%). However, the overall conclusion as stated above remains unchanged when focussing on FSI crashes. As can be seen from Figure 9 (similar figure in Hovenden et al., 2020), in the higher occupancy ranges (15% and above), the FSI crash numbers were exceeding the exposure level and they were lower than the exposure level for the occupancy bin between 10% and 14.9% where the breakdown risk is still relatively low (that is, <= 1% per 15-minute interval) and where it hasn't broken down yet. Based on a larger sample, the target operational state (i.e. occupancy value) should be determined within this occupancy range so that safety as well as efficiency can get optimised.

A complementary piece of pioneering work that focuses on vehicle-based event identification was undertaken by Gitelman et al. (Gitelman et al., 2016). This study explored the relationship between driving events produced by in-vehicle data recorders (IVDR), road characteristics and crashes, to examine a potential of the events for predicting crashes and identification of high-risk locations on the road network. The study database included 3,500 segments of the interurban roads in Israel, for which the automatically produced IVDR events were matched with road infrastructure characteristics and crashes.

The study focused on 'Braking' and 'Speed alert' events but also identified additional ones such as 'Lane change' (in total 20 event types). Considering an event-crash relationship the authors found that, under certain road conditions, driving event counts can contribute to the prediction of crash occurrences. For single-carriageway roads, better explanatory potential for predicting both injury and total crashes was found for 'braking' events and the total events, which were positively related to crashes (i.e. the more braking or other events, the more crashes).

For **dual-carriageway roads**, for predicting various crash types, the 'speed alert' events are more suited, where those are negatively related to crashes (i.e. the more 'speed alert' events, the fewer crashes). In addition, 'braking' events can be applied for predicting injury crashes on this road type, for which a positive relation to crashes is expected. For **freeway / motorway road segments**, the 'speed alert' and total events are applicable for predicting crashes, where a negative event-crash relation is expected. These results are in line with the engineering judgement as more 'braking' events are associated with worse road conditions and more interrupted travel that may lead to more crashes, whereas more 'speed' events actually reflect better road conditions, with low junction proximity and non-interrupted travel, that is generally associated with lower crash rates.

Unfortunately, according to the authors, the amount of recorded lane change events was very small and not sufficient for conducting a separate analysis. It should be noted that only 32% of the roads investigated were freeways, all of them with 2 lane carriageways which indicates a relatively low number of lane changes (refer to "Lane changes as an example of countable event" below).

Some conclusions from the works quoted are as follows:

- There are certain traffic states such as high density/occupancy that should be avoided, e.g. through appropriate planning or real-time traffic control, both limiting oversaturation (macro level)
- It would be desirable to gain more knowledge about which individual vehicle-based events cause crashes (micro level) because the mechanisms that create dangerous conditions are much more complex than can be seen on the macro level
- It would be feasible to carry out a vehicle- or infrastructure-based event study which focuses on multi-lane motorway carriageways with lots (thousands) of lane changing and traffic condition related braking events etc (also refer to Section 'Lane changes as an example of countable events' – 'Measurement'). It is expected that this would allow for the establishment of robust relationships between Number of crashes ('Effect') and events as elementary Unit of Exposure ('Cause').

Events of exposure

The previous sections have endeavoured to explain what makes traffic on urban motorways complex. Density or occupancy is a robust but relatively rough (macro) indicator for traffic complexity and the corresponding safety issues. Linking the magnitude (or number) of individual vehicle actions (micro) to both is the next logical step.

Theory

Generally, analysis of the absolute crash number is a suitable means to identifying problematic locations, times (e.g. hours of the day) or traffic conditions. This can be simply done based on crash records including the conditions under which crashes happened if retrospective crash analysis is being done. However, with regards to generalising such observations, (e.g. forecasting the expected number of crashes) for new or amended facilities or under changed operational conditions (e.g. increased AADT), the analyst relies on a model that revolves around a robust relation between causation and effect (i.e. crash causation). This is currently usually based on Equation (1) above. The expected number of crashes can then be estimated as per Equation (2):

Number of Crashes = Crash Rate * Unit of Exposure (or 'Exposure') (2)

Elvik in his paper titled 'Towards a general theory of the relationship between exposure and risk' (Elvik, 2014) exposes commonly used metrics like the 'traditional crash rate' (with VKT used as the Number of Events of Exposure) as not being an appropriate tool to control the number of crashes since VKT (or AADT/hourly volume) is only one component that (indirectly) influences the occurrence of crashes. Usage of the traditional crash rate is unsuitable to establish a direct (or linear) relationship between causation (i.e. high VKT/AADT/traffic volume) and effect (i.e. high number of crashes). Establishing such a relationship is not only important to forecast the expected number of crashes (as explained above) but even more so to establish suitable measures for crash reduction including operational ones.

Elvik outlines that exposure can be defined as any event that generates an opportunity for an accident to occur. Events form elementary units of exposure, i.e. once identified, events can be counted, and their total number determined. Thus, events represent trials in the sense of that term in probability theory. In a previous paper (Elvik et al., 2009) four types of events were defined:

1. Encounters (e.g. vehicles travelling in opposite directions on an undivided rural road)
2. Simultaneous arrivals from conflicting, or potentially conflicting directions of travel
3. Changes of direction of travel close to other vehicles or road users
4. Braking or stopping

Type No. 3 includes lane changes. Type No. 4 may get caused by vehicles travelling at high speed that encounter a shockwave. Complexity needs to be countable (as events or elementary units of exposure) and in the case of planned changes to conditions also predictable in order to be a useful concept.

In terms of an outlook on practical consequences, it may be speculated that the corresponding crash rate for 'braking' could be influenced by better enforcement for the elimination of extreme speeding events. As for example stated by Hovenden et al. (2020), 'over the one-month period, from 20 February 2017 to 20 March 2017, around 180 motorcycles travelled at speeds between 130 km/h and 205 km/h on the inbound and outbound carriageways of the Monash Freeway near Stanley Street'.

Application

The vision that the authors have is that the relation between cause (more suitable Number of Events of Exposure than VKT) and effect (crash occurrence) can be established such that:

- (Non-traditional) crash rates can be determined for the different events (or event combinations)

Figure 10. Monash Freeway Dynamic Variable Speed Limit (DVSL) and potential extension by real-time warnings of congestion ('Stau'), inclement weather conditions etc as realised in Germany (Source: VicRoads)

- Conditions with a high Number of Events of Exposure can be identified for present or future (planned) conditions, and combined with the crash-risk the number of crashes can be predicted; these conditions can be spatially fixed such as critical lane configurations (refer to "Lane changes as an example of countable event" below), lengths, points (e.g. critical weaving areas that are too short to accommodate the needed number of conflicting lanes changes) or situational such as characterized by high volume-to-capacity (v/c) ratio, occupancy etc.
- Concepts for the reduction of a concentration of Events of Exposure as well as projects or programs can be developed and appropriately justified and prioritised (i.e. classical road improvement projects, or ITS/ traffic management implementations including real-time warnings of hazardous conditions that are 'likely resulting in a reduced reaction time'; refer to Figure 10 and Cunningham et al., 2017).

Lane changes as an example of countable events

Estimation of the quantum

There is general acknowledgement that lane changing, especially when performed aggressively in heavy traffic conditions, can cause significant turbulence (or oscillations) on motorway flows (refer to Ahn and Cassidy, 2007). This can impact efficiency and sometimes also safety (refer to Hovenden et al., 2018). However, a minimum level of lane changing is required to load and unload all lanes across a motorway carriageway. It is important to **measure**, **analyse** and **understand** it so that corresponding strategies to avoid these impacts can get developed. The scale of lane changing is currently not well understood.

As mentioned in the Section 'Studies of the relation between complexity and crashes', in the detailed free-text descriptions and images provided by the Police, mention was regularly made of vehicle blind spots. As crashes are rare events resulting from thousands of interactions between vehicles, it is helpful to understand the quantum of such interactions on urban motorways.

There are a high number of lane changes needed to fill all lanes of an urban 4 lane carriageway to capacity (2,500+ lane changes per kilometre and hour, refer to Figure 11). This, combined with the high traffic volumes (up to around 8,000 vehicles per hour, refer to VicRoads, 2019), means that many lane changes must occur under situations where the nearby vehicles in adjacent lanes are within the blind spot zone at some stage between the decision to lane change and the making of the lane change manoeuvre itself. This requires cooperation of other drivers to adjust speeds etc. for the lane change manoeuvre to be safe. As shown the quantum of these 'mandatory' lane changes increases exponentially with increasing carriageway lane number.[1]

The underlying reason for this is that vehicles must pass through the outer lanes in order to fill the inner lanes and there is also an increase in the number of conflict points (refer to Figure 12).

Measurement

Researchers are increasingly interested in quantifying the number of lane changes in traffic. For example, Knoop et al. (2012) based on a limited sample size observed around 0.5 lane changes per vehicle, kilometre and hour.

Recent implementation of advanced and highly accurate **infrastructure-based** vehicle detection technology is creating new opportunities to understand the dynamic of traffic interactions at the individual vehicle level. A key opportunity emerging is the ability to measure lane changing activity between two detector sites using vehicle re-identification under high flow conditions. Figure 13 shows the general set-up of such side fire infra-red-light detection.

Each detector site consists of two electronic devices (receiver and transmitter units) mounted on either side of a

1 VicRoads investigations suggest that the average urban motorway trip length is around 15 kilometres which for the 4-lane carriageway example results in a per kilometre number of lane changes of 38,000 /15 = 2,533

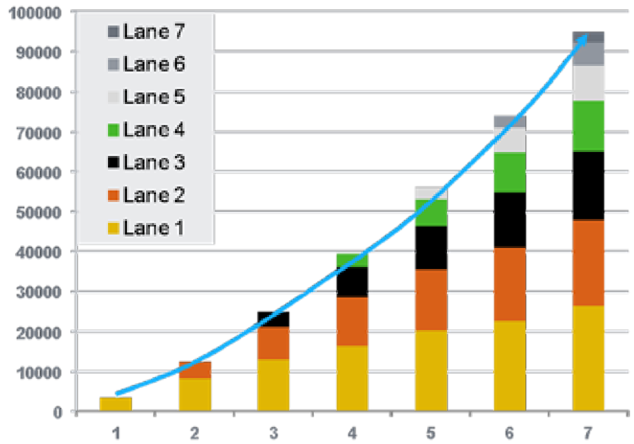


Figure 11. Quantum of lane changes (indicative) by lanes (median lane is at the top of bar). (Source: VicRoads, 2020)

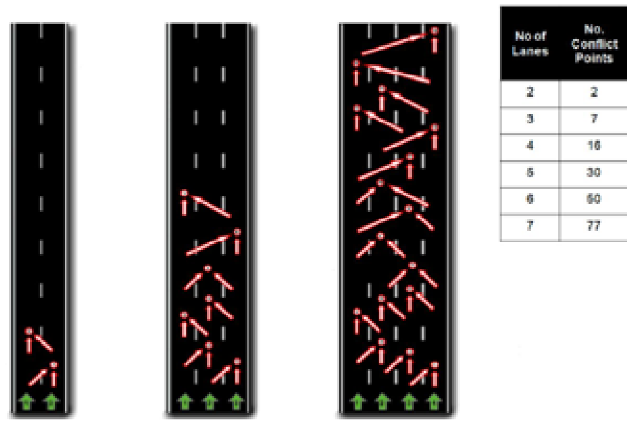


Figure 12: Number of conflict points in relation to the number of lanes (Source: Kononov et al., 2016)

Figure 13. TIRTL Detector – Actual Device (L) and Installed in Housing (R) (Source: Hall et al., 2018)

road. In total, it uses four infra-red-light beams (two straight and two diagonal ones) passing above the road surface to detect and record vehicles and their respective attributes (refer to CEOS).

TIRTL detection allows individual vehicle events to be logged along with a wide variety of information about each vehicle including the wheel base and axle configuration and the lateral position of the vehicle in the carriageway (implying the lane occupied). With similar data collected at two sequential TIRTL detection locations, it is theoretically possible to attempt to match individual vehicle attributes at both sites and determine whether the matched vehicle has changed lanes between the two sites.

Figure 3 shows the total five-minute lane change movements measured over a 480m section of the Monash Freeway using lane change matching from vehicle re-identifications techniques. In the VicRoads study, typically, 100 lane changes were measured over that time and distance during periods of lighter traffic volume periods in the middle of the day. This equates to 2,400 lane changes per kilometre and hour.

This technology has already been rolled-out on large parts of the metropolitan Melbourne motorway network with a focus on the Monash and Princes Freeways (refer to Figure 14).

Similar to the analysis carried out to establish a relationship between occupancy and crash occurrence (refer to Hovenden et al., 2018), such data could be used to robustly link lane changing intensity to crash occurrence.

Mitigation of complexity

The following paragraph is an outlook on potential complexity mitigation measures from a road operator's perspective. Its purpose is to illustrate potential practical consequences of the intended research. As this research is ongoing, it is limited to some non-exhaustive examples.

Infrastructure based

In order to meet capacity requirements, there are sometimes alternative carriageway lane configurations possible. For example, instead of building a 6-lane carriageway it is sometimes technically feasible to build a 2-lane and a 4-lane carriageway (refer to Figure 15) which not only increases capacity (refer to Maximum Sustainable Flow Rate values for 6 and 2+4 lanes in Figure 16) but also reduces the number of conflict points and lane changes (refer to Figure

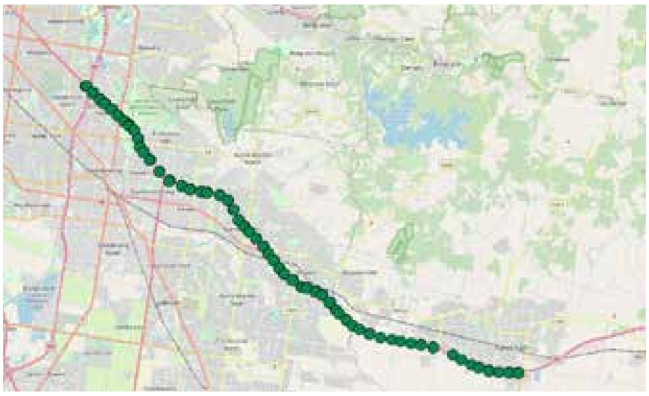


Figure 14. Roll-out of TIRTL Detectors (Source: CEOS, 2019)

Figure 15. 2+4 rather than 6 lane carriageway configurations for reduced number of conflict points and lane changes (Source: VicRoads)

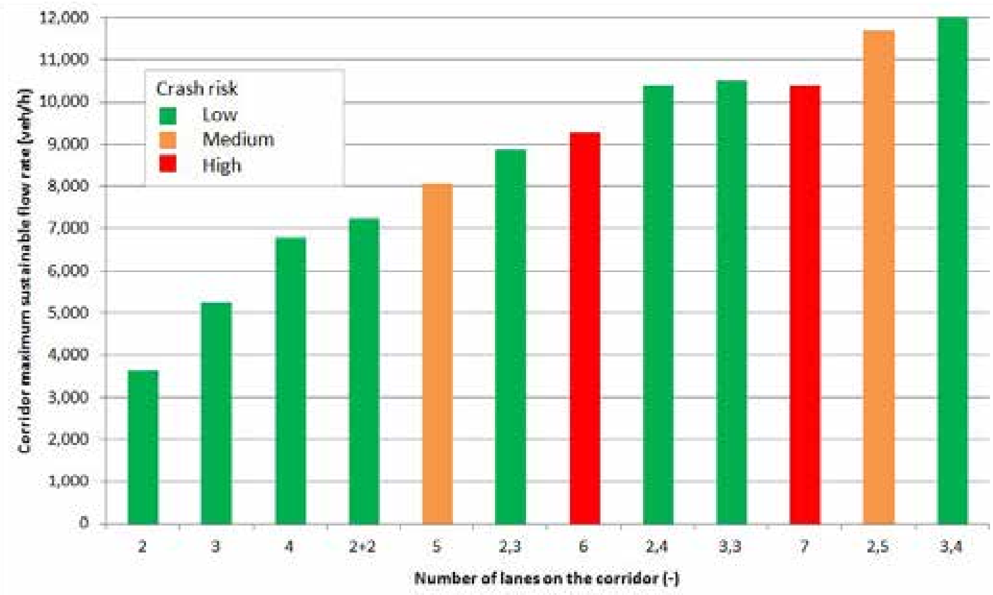


Figure 16. Corridor Maximum Sustainable Flow Rates ('capacity') under various lane configurations (Source: VicRoads, 2019)

11 and Figure 12). This is now part of VicRoads guidelines (refer to VicRoads, 2019).

Technology based (present and future)

Advanced Driver Assistance Systems (ADAS)

On the individual vehicle level (micro), the introduction of Advanced Driver Assistance Systems, such as Automated Emergency Braking (AEB) to tackle rear-end crashes and Blind Spot Warning to tackle lane change and side swipe crashes, could be accelerated to improve motorway safety. There is no further discussion of these important technologies here as it is assumed that this is common knowledge among road safety experts. It appears that such technologies do not reduce driving complexity at the source but rather help dealing with the symptoms, i.e. reduce the cognitive workload for motorists.

Network control

Melbourne's M1 Freeway Upgrade project included the implementation of a new coordinated ramp signalling system, with signals at 64 ramps coordinated via the City-Wide Coordinated Ramp Metering System (CWCRM) control strategy, as well as lane use management to implement all lane running (following civil upgrades). A before-and-after-upgrade evaluation was undertaken that considered the combined change in (per lane) throughput and average speed (i.e. gains in 'productivity' which is the mathematical product of throughput (flow) and speed, refer to Austroads, 2007). For the M1 Upgrade, the peak hour productivity gains were 41.6% for the inbound direction and 48.1% for the outbound direction (refer to Gaffney et al., 2017, Appendix A.1 for more detail).

The evaluation also showed a crash rate of 9.15 crashes per 100 m VKT for the five years spanning 2001 to 2005, which preceded the M1 project, compared to a crash rate of 6.31 crashes per 100 m VKT in the five years between 2010 and

2014 which were after the M1 project (refer to Gaffney et al., 2017).

The aim of the coordinated ramp signalling system is to reduce the exposure to the higher traffic (or density/occupancy) ranges. For this, vehicles are temporarily stored at on-ramps to avoid occupancy peaks. It should be noted that technically, occupancy rather than density is controlled by the CWCRM system as it can be directly measured at detector sites.

The following mechanisms contribute to enhanced safety:

- At on-ramps, vehicles are released into the motorway at a certain distance of each other, i.e. they are not released as platoons, hence the number of critical vehicle interactions is reduced
- Avoidance of density or occupancy spikes limits the need for critical braking manoeuvres, in particular when flow breakdown and congestion is avoided

Despite the positive impact on safety as described above, there is still room for improvement through better control by further reducing the occurrence of congestion and shockwaves causing harsh braking manoeuvres and by potentially defining operational targets at lower occupancy values where the amount of lane changing is reduced. The system is technically capable of avoiding any congestion and hence shockwave occurrence (except those created by incidents), however optimised mainline flow conditions need to be carefully balanced with on-ramp queueing that may affect other critical infrastructure (e.g. blocking a crossing multi-lane arterial that carries a tram line). It is noteworthy that the success of the CWCRM is recognized internationally, as for example evidenced by the concept currently being implemented in Colorado, USA.

Similar concepts that primarily aim at avoiding oversaturation through temporarily storing or re-routing vehicles before entering a critical (sub-) network have also been developed for non-motorway arterial roads (‘perimeter control’). These in principle work through ‘gating’ at traffic signals at the circumference of such gated networks (refer to Geroliminis et al., 2013) in order to avoid too high density and optimise throughput. The authors hope that such gating can also be used to optimise the number of inter vehicle interactions and hence limit the crash risk (refer to Alsalhi et al., 2018).

Discussion

There are certain safety-critical traffic states such as high density/occupancy that should be avoided, e.g. through appropriate planning or real-time traffic control, both limiting oversaturation (macro level).

What is less clear are the microscopic mechanisms that cause safety issues. This requires a robust analysis on the next or individual vehicle level (micro level).

New insights are now possible due to advances in **infrastructure-based** event detection technology as well as in **vehicle-based** event identification (e.g. in-vehicle data recorders (IVDR)).

In Victoria, such advanced infrastructure-based technologies are rolled-out as part of the normal managed motorway ITS technology so that they are suitable for observations on entire motorway corridors over long periods which is essential for robust analysis. Hence it is a realistic prospect that the lane changing and potentially also the ‘harsh braking’ rate will soon be a traffic flow parameter that is as important as speed (km/h), volume (veh/h) and occupancy (%). These rates can then be analysed in similar ways such as through the determination of the following parameters:

- Average peak hour lane change event intensity per urban motorway section (historical analysis for comparative purposes)
- Usage of measured real-time lane change event intensity for traffic control

It appears that vehicle-based event identification with IVDR allows for the analysis of a greater number of different event types (e.g. ‘Braking’ and ‘Speed alert’). However, data generation and analysis will likely be limited to dedicated studies in the foreseeable future and the permanent and network wide availability of measured real-time or historical data is a more distant prospect.

Conclusion

The dynamic of the traffic flow induces an increased complexity of the traffic itself as well as of the driving task which contributes significantly to the increasing number of crashes as human as well as vehicle performance capability has limitations. However, the microscopic (i.e. individual vehicle based) mechanisms that make such traffic states complex and therefore cause safety issues need to be further explored. Due to advances in infrastructure-based event detection technology and vehicle-based event identification there is a good chance for successful additional research in this area.

More than two thirds of the crashes on metropolitan Melbourne motorways analysed were rear end crashes, lane change or side swipe crashes that maybe linked to braking or lane change events. It would be worthwhile to determine crash rates for these events. This would enable robust justification of mitigation measures so that too high event concentrations can be avoided through appropriate roadway planning or traffic management including real-time control.

It is expected that under urban motorway conditions linking the number of events of exposure (e.g. ‘harsh braking’ or lane change events) to crash numbers can provide more insights into the relationship between causation and effect than is the case with the traditional crash rate (VKT based). Establishing such a relationship is not only important to forecast the expected number of crashes but even more so to establish suitable measures for crash reduction including operational ones.

The concepts developed for urban motorways are also applicable to other high-volume multi-carriageway roads, e.g. in peri-urban areas and, based on existing arterial road network traffic control concepts ('perimeter control'), it may be possible to develop similar concepts for road safety optimisation on non-motorway arterial road networks.

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