Vol 28 No 1, 2017

Journal of the Australasian College of Road Safety

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Peer-reviewed papers

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Australasian College of Road Safety

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Cover image

This photograph shows a fatal crash scene facing the opposite direction of travel by Karl and his wife Wendy. Karl was driving home in the late afternoon with Wendy after her birthday lunch. They came around the left-hand curve where water was pooling and the road edge had deteriorated, aquaplaned just after the 45 km/h advisory sign, bounced off the left hand curb over to the right where there was no barrier, and rolled down a steep bank into the tidal creek of a river where Karl drowned. See the Perspective on Road Safety article as a tragic illustration of a system failure reminding us to stop blaming road users for inevitable human mistakes (Mooren, L. (2017). Tragic Failure of a Road System: An Australian Example. *Journal of the Australasian College of Road Safety, 28*(1), pages 58-64.).

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Managing Editor: Dr Chika Sakashita
Australasian College of Road Safety & Global Road Safety Solutions
1080 Wisconsin Ave NW #3009, Washington DC, 20007, USA
journaleditor@acrs.org.au

Peer-Review Editor: Prof Raphael Grzebieta (FACRS)
Transport and Road Safety (TARS) Research, University of NSW (UNSW) West Wing, 1st Floor, Old Main Building (K15), Sydney NSW 2052 Phone +61 (0)2 9385 4479 r.grzebieta@unsw.edu.au

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Editorial Policy
The *Journal of the Australasian College of Road Safety* aims to publish high quality papers and provides a means of communication for the considerable amount of evidence being built for the delivery of road safety, to inform researchers, policymakers, advocates, government and non-government organisations, post-crash carers, engineers, economists, educators, psychologists/behavioural scientists, communication experts, insurance agencies, private companies, funding agencies, and interested members of the public. The Journal accepts papers from any country or region and has an international readership.

All papers submitted for publication undergo a peer-review process, unless the paper is submitted as a *Perspective*/*Commentary on Road Safety* or *Correspondence* or the authors specifically request the paper not to be peer-reviewed at the time of original submission. Submissions under the peer-review stream are refereed 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. Papers that pass the initial screening process by the Managing Editor and Peer-Review Editor will be sent out to peer reviewers selected on the basis of expertise and prior work in the area. The names of the reviewers are not disclosed to the authors. Based on the recommendations from the reviewers, authors are informed of the decision on the suitability of the manuscript for publication.

When papers are submitted and the authors specifically request the paper not to be peer-reviewed at the time of original submission, the papers will be published under the non peer-review stream. Submissions under the non peer-review stream, *Perspective*/*Commentary on Road Safety* and *Correspondence* are reviewed initially by the Managing Editor, who makes a decision, in consultation with the Peer-Review 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 editor/s.

As a rule of thumb, all manuscripts can undergo only one major revision. Any editorial decisions regarding manuscript acceptance by the Managing Editor and Peer-Review Editor are final and further discussions or communications will not be entered into in the case of a submission being rejected.

For all articles which make claims that refute established scientific facts and/or established research findings, the paper will have to undergo peer-review. The Editor will notify the author if peer-review is required and at the same time the author will be given the opportunity to either withdraw the submission or proceed with peer-review. The Journal is not in the business of preventing the advancement or refinement of our current knowledge in regards to road safety. A paper that provides scientific evidence that refutes prevailing knowledge is of course acceptable. This provision is to protect the Journal from publishing papers that present opinions or claims without substantive evidence.

All article types must be submitted online via the Editorial Manager: http://www.editorialmanager.com/jacrs/default.aspx. Online submission instructions can be downloaded from: http://acrs.org.au/contact-us/em-journal-conference-contacts/.

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It is essential that authors writing for the Journal obtain and follow the ***Instructions for authors***. These are updated regularly and can be downloaded from the College website at http://acrs.org.au/contact-us/em-journal-conference-contacts/

Authors are responsible for complying with all the requirements (including Article types, Article structure, References, Ethics in publishing, Originality & plagiarism, Author declaration) before submitting their papers. The College has adopted guidelines developed by the Committee on Publication Ethics, which are available at http://acrs.org.au/publications/journals/ethics-and-malpractice-statement/.

ACRS office contact details
Mrs Claire Howe, Executive Officer, eo@acrs.org.au: For inquiries regarding membership and College activities.

Dr Chika Sakashita, Managing Editor, journaleditor@acrs.org.au: For inquiries regarding submissions, current and back issues, advertising and sponsorship for the Journal.

Ms Christine Bethwaite, Finance and Administration, faa@acrs.org.au: For inquiries regarding Journal subscriptions and changes of postal address.

Mailing address: PO Box 198, Mawson, ACT 2607 Australia
Phone: (02) 6290 2509
Head office: Pearce Centre, Collett Place, Pearce ACT Australia

From the President

Dear ACRS members,

I am delighted that Dr Chika Sakashita has been appointed as our Managing Editor and congratulate and thank Laurelle Tunks for her contribution in that role since 2012.

I have reflected on my introductory comments to the Journal over the years on road safety research and actions.

In my first Column in 2008 I reported that I had written to the Prime Minister seeking direct support for a whole of government approach to reduce road trauma and offering the College support for any national road safety initiatives.

This approach was not new. Your past President Raphael Grzebieta had made similar requests as had the College in earlier times.

The same message continues today. Unfortunately, the response has not changed. We seem to be inflicted with the "two steps forward, one step back" policies on road safety.

Late last year I posted a Christmas road safety message on LinkedIn, recognising that it is almost impossible to find a national media outlet interested in a comprehensive approach to road safety. (https://www.linkedin.com/pulse/road-safety-messages-christmastime-more-than-just-blame-mcintosh?trk=prof-post). I based the message on a quote by Dr William Haddon, which is prominently displayed at the Insurance Institute of Highway Safety in Virginia in the USA. "It is time for society to decide to promote and demand nothing less than vehicle packages and roadside environments that protect people." Dr Haddon was President of the Institute from 1969 to 1985 having served at the National Highway and Safety Administration.

Last year was the 50th anniversary of Ralph Nadar's famous book "Unsafe at Any Speed". Most of us recall the book being focused on car safety…or "unsafety". But Ralph also had a chapter "The Traffic Safety Establishment" which I commend to you. He said 50 years ago US road safety policy "suffers from inadequate legislative authority of the groups that are required to administer it, from insufficient funds allocated to the effort, and from lack of administrative consolidation that could launch a concrete program that would have the same kind of high level support that complex programs in atomic energy and space programs have."

This edition has papers which, like many others published in the Journal over time, show us a way forward. We know what can be done; we need to get out of the blame game and implement solutions. It has been too easy to focus on blaming the driver. There is no doubt that drivers make mistakes, that they can be distracted and they break reasonable rules. But as Rex Whitton the US Highway Administrator said in 1963 (quoted in Nadar); "I believe that because of these attacks (on the drivers), our attention is being distracted and our energy is being diverted from the essential things we could and should be doing to reduce the traffic accident toll".

The College is still seeking a whole of government approach to road safety in our submission to the Federal Treasury for a reallocation of a relatively small component of the massive infrastructure budget to ensure we can have a high level, nationally coordinated concrete road safety program in 2017.

We deserve nothing less.

Lauchlan McIntosh AM FACRS FAICD
ACRS President

From the Editors

Recent improvements made to the *Journal of the Australasian College of Road Safety*

Happy New Year! This February 2017 Issue marks the first edition of the *Journal of the Australasian College of Road Safety* in 2017 and as of this Issue we have a new Managing Editor on board.

With these new beginnings, we would like to share with you the exciting changes the *Journal* has been undergoing. We have implemented these changes to ensure that making a submission in the correct format is now easier, to allow for a greater range of article types, and to increase the rigor of our reviews in order to strengthen the quality of the papers published. You may be aware of these changes that have been occurring in the past months regarding the *Journal*:

1. Renewed Author Instructions introduce new article types to further guide authors in preparing submissions to the *Journal*;
2. A new Word Template assists authors in preparing submissions meeting the *Journal* formatting requirements;
3. Launch of the online portal for submissions to the *Journal*: Editorial Manager;
4. Guide on how to make online submissions to the *Journal* via the Editorial Manager;
5. Higher standards of peer-reviews via the Editorial Manager for peer-review submissions;
6. Reviews by the Editor/s via the Editorial Manager for non peer-review submissions.

All the above mentioned documents can be found at http://acrs.org.au/contact-us/em-journal-conference-contacts/ (scroll down).

We are endeavouring to raise the standard of the *Journal* to become one of the highest calibre scientific journals in road safety. This in turn will help us secure listing in the Journal Citation Reports and Web of Science with the eventual outcome of obtaining a much desired impact factor (IF) for the *Journal*. We have also scheduled a review of the Editorial Board to further assist us with this task. If you have an excellent track record in road safety and willing to roll up your sleeves serving on the Board, we would be keen to hear from you. Authors of the *Journal*, peer-reviewers and Editorial Board members who generously donate their valuable time have been a key to our continued growth and success and we very much appreciate the excellent expertise and experience you bring to our *Journal*.

We are focused on continuing to expand the *Journal*'s readership and the pool of authors and peer-reviewers so that the readers of the *Journal* can continue to enjoy reading and learn about the considerable amount of evidence being built for the delivery of road safety as well as the College activities.

While the College resources are very limited, we are doing our best to bring you a valuable *Journal* and we appreciate your patience and cooperation in this transition process. If you have questions or feedback, please contact the Managing Editor journaleditor@acrs.org.au.

We sincerely appreciate your contributions to date, and we look forward to your continued active participation as authors, peer-reviewers, and/or readers of the *Journal*.

Dr Chika Sakashita, PhD
Managing Editor

Prof Raphael Grzebieta, PhD
Peer-review Editor

Chapter reports

Chapter reports were sought from all Chapter Representatives. We greatly appreciate the reports we received from ACT, NSW, Queensland, Victoria and Western Australia.

Australian Capital Territory (ACT) and Region

Drug driving

As outlined in our last report, the Chapter had managed the 2016 Road Safety Forum on Drug Driving for the ACT Justice and Community Safety Directorate. A report on the Forum was prepared for the ACT Minister for Road Safety.

Following receipt and consideration of the report, Minister Rattenbury requested JACS to establish three working groups to focus on the areas of: education and communications; research and data; and drug driving regulation (including penalties and an impairment based approaches to regulation). The Chapter is participating in these working groups. The first, education and communications, is due for completion around the end of March 2017 and the others by the end of the year.

Reducing the risks - Cyclists, Pedestrians and Buses/Heavy Vehicles

The Chapter is discussing with ACT Government Departments the development and management of a workshop aimed at t reducing the risks of crashes between buses, heavy vehicles and vulnerable road users. The workshop will bring together people representing each group with actual experiences so that they can explain first hand these experiences and together work out strategies on how all involved can better understand each other's concerns and propose positive ways of alleviating the risks.

The workshop is proposed for the end of February 2017.

Vale John Bonnett

The road safety community lost one of its champions with the recent death of John Bonnett following a courageous twenty-year battle with cancer. John first became involved with road safety when he joined the Federal Office of Road Safety (FORS) in the early 1980's. There he worked on a range of public education campaigns targeting primary schools, motorcyclists and older pedestrians. John led this latter campaign – a difficult group to target particularly as older people tend to think of themselves as not being old!!

Even after leaving FORS John's interest in road safety never waned and he became an active member of the ACT & Region Chapter of the College. He was also an active member of the Motorcycle Riders Association of the ACT (MRA), John loved motorcycles from his early childhood days - with his father owning an Indian motorcycle. When the movie 'The World's Fastest Indian' was released a few years ago John made sure he did not miss it. John was deeply committed to motorcycle safety. He worked with the MRA and Stay Upright to develop the MASTERS course (Mature Aged Skills Training for Experienced Riders). This program was specifically aimed at mature riders either returning to motorcycle riding after a long break or riding for the first time.

The NRMA – ACT Road Safety Trust helped fund the course. It was launched by Robert De Castella in 2003 and attracted national interest from motorcycle bodies. In 2005, John presented a paper on the program at the Australasian Road Safety Conference in Wellington, New Zealand. The MRA continues to offer the program.

The College extends its condolences to John's widow Kathy, and his two sons Kevin and Jonathan, on behalf of the road safety community.

ACT Chapter Secretary
Mr Keith Wheatley

New South Wales (NSW)

The NSW Chapter Committee experienced several changes during 2016 due to a combination of representatives retiring or changing jobs.

Long-time member of the Committee, Jack Haley, retired from his role at NRMA and so did not re-stand at the 2016 Annual General Meeting. Jack's departure from the NSW Chapter Committee has left a significant gap in the Committee's representation. On behalf of all NSW members, the Committee wish to thank him for his many years of support and commitment to the ACRS, and wish him well in his retirement.

Duncan McRae (Youthsafe), Lauren Meredith (NeuRA) and Garret Mattos (UNSW) also did not re-stand at the 2016 AGM with the need to focus on work and family. Ben Barnes (Transport for NSW) resigned from the Chapter Committee following a change of career away (temporarily, at least) from road safety.

The Committee welcomes new representatives to the Committee Alexandra Hall (NeuRA), Soufiane Boufous (UNSW) and Graham Knight (RIDE IT RIGHT), who now complement the other Committee members – David McTiernan, Brendyn Williams, Teresa Senserrick, Liz de Rome, Lisa Keay.

The NSW Chapter had a relatively active year in 2016 hosting or co-hosting a number of seminars for ACRS members and also preparing and making submissions to Government on issues of interest and relevance to the Chapter membership.

Seminars included:

- Safe System Roads for Local Government by David McTiernan of ARRB Group
- Young Drivers Seminar and Discussion Panel with visiting overseas speakers, Dr Bruce Simons-Morton, outgoing Chief of the Prevention Research Branch of the National Institutes of Health in the United States and Dr Willem Vlakveld, senior investigator at the SWOV Institute for Road Safety Research, The Netherlands, jointly with Transport and Road Safety Research, UNSW.
- Smartphone-Based Teen Driver Support System: Results from a 300 teen driver field operational test, with visiting Professor Max Donath from University of Minnesota, jointly with Transport and Road Safety Research, UNSW.
- Human Factors and Advanced Vehicle Technologies, with international guest, Professor Birsen Donmez from the University of Toronto, jointly with the School of Aviation, Transport and Road Safety Research, UNSW
- Identifying Serious Injuries due to Road Crashes featuring international guest, Wouter Van den Berghe, Belgium Road Safety Institute, and Hassan Raisianzadeh, Transport for NSW, jointly with Transport and Road Safety Research, UNSW
Submissions made by the Chapter included:
- To the NSW Staysafe (Joint Standing Committee on Road Safety) Inquiry into Motorcycle Safety in NSW, and attendance to provide verbal evidence (Dr Liz de Rome and Mr Duncan McRae.
- To the NSW Premier seeking information about plans for NSW to expand the point-to-point speed camera enforcement program to cover all vehicles, not just heavy vehicle classes.

As a final acknowledgement of the work of the NSW Chapter, three members - David McTiernan (ARRB Group), Lisa Keay (George Institute) and Ben Barnes (Transport for NSW) - were on the Scientific Committee for the Australasian Road Safety Conference 2016, contributing to the quality and rigour of the papers and presentations at the National Conference.

NSW Chapter Representative
Mr David McTiernan

Queensland (QLD)

The Queensland Chapter held a seminar and Chapter meeting on 6th December 2016. We had two speakers reporting on two very different conferences.

> Clare Murray, Principal Advisor (Communications), Queensland Department of Transport and Main Roads
>
> *Safety 2016 Conference* - Injuries, both violence and unintentional injuries, are a major burden on public health worldwide. While experts in injury prevention and safety promotion recognise the need for action,

the state-of-the-art knowledge and practice from these fields are not consistently applied to policies and programmes in the field. The main theme for the Safety 2016, "From research to implementation", sought to provoke new ideas and experiences to address this gap.

Emeritus Professor Mary Sheehan, CARRS-Q

T2016- the 21st International Council on Alcohol, Drugs and Traffic Safety (ICADTS) Conference set an excellent opportunity to increase interest and commitment to research and policy development in Drugs and Alcohol in LMIC. This focus began at T2013 in Brisbane and it now has become one of the central initiatives of the ICADTS Strategic Plan. It was a small, highly focussed conference that included leading international investigators, academics and professionals working in this area. Key topic issues will be presented for the interest of College members.

The last part of the 2016 saw Queensland Chapter members involved in a range of conferences, following the Australasian Road Safety Conference.

- Several members attended the Safety conference in Finland, including Clare Murray, who was sponsored by the Chapter and has provided a report on some of the significant messages from the conference.
- Chapter members also played a significant role at T2016, the conference of the International Council on Alcohol, Drugs and Traffic Safety, held in Brazil in October. The Council's immediate past President is Mary Sheehan, while Narelle Haworth sits on the Council.
- In December the Chapter President represented ACRS at the Queensland Minister for Road Safety's "Safer Roads, Safer Queensland" forum, along with other stakeholders, to discuss the implications of a shift to an injury target for road safety and how this might be reflected in the forthcoming Action Plan to be released by the Minister.

QLD Chapter Representative
Dr Mark King

Victoria (VIC)

The Victorian Chapter has enjoyed a successful year with the conduct of three seminars, development and conduct of the "Family Feud" session at the National Conference as well as preparing and tendering a submission to the Victorian Parliamentary Committee on the issue of lowering the licence age to 17 years. The ACRS was also represented at a Federal Senate Committee hearing with regard repealing the mandatory bicycle helmet laws across Australia. College chapter committee members have been especially active in supporting all these activities.

Seminars conducted covered the issues of bicyclist safety, a global perspective on road safety as well conduct of a Victorian-based "Family Feud" session. Attendances in the order of 30 to 100 have attended each seminar. We have varied the times of the sessions as well as the location in order to determine what combinations best suit member attendance. We have also taken the opportunity at each session to encourage non-members to become members of the College.

Joining forces with the Institute of Transportation Engineers resulted in a very successful seminar on "Global Perspectives on Road Safety" in which professionals from academia and government described the learnings they valued from overseas assignments. The second seminar was the trial of the family feud idea which was deemed to be both engaging and informative; the concept was then further developed into a workshop at the National Conference in Canberra. The bicyclist safety seminar involved presentations by bicycle advocacy groups, transport consultants and government and was very well attended and attested to the growing interest in providing sustainable development in which safe walking and cycling are encouraged. Through the great assistance of the committee membership, this last seminar was filmed with a view to uploading presentations onto the College Youtube site and so becoming available to all members to view. The Chapter is looking to continue this practice for future seminars.

The Chapter is very interested in building an active membership and continues to explore ways in which additional people both working in the road safety field or take a keen interest in safety issues can be further supported and engaged via College activities.

I would like to thank all those members of the Victorian Chapter who have given so freely of their time in helping to make our activities as successful as they can possibly be. My special thanks go to Melinda Spiteri, the Chapter Chair currently on maternity leave, Wendy Taylor, Kenn Beer, Marilyn Johnson, Jude Charlton, Greg Rowe, Sam Buckis, Anne Harris and Richard Tay for their on-going support of College events.

Finally, I would also like to express my thanks for the great continuing support given by Claire, Lauchlan and staff of the National Office.

We are looking forward to the coming year with a focus on improving our engagement with those interested or involved in road safety in Victoria, increasing our membership as well as advocating for good safety policy with key decision makers.

VIC Chapter Representative
Mr David Healy

Western Australia (WA)

In the first half of the year the WA Chapter of the ACRS and the Curtin-Monash Accident Research Centre co-hosted two important road safety seminars.

On the 2nd **March 2016,** Dr David Logan, Senior Research Fellow with the Monash University Accident Research

Centre, presented an update on the eMETS (Enhanced Macro Estimates for Target Setting) modelling project. Based on the ideas of Monash University Accident Research Centre (MUARC) founding director Peter Vulcan and Dr Bruce Corben, the Macro Estimates for Target Setting (METS) model was developed in the mid-2000s and used to assist with the development of the WA Towards Zero strategy during 2007.

Since that time METS has been applied successfully to several jurisdictions throughout Australia and New Zealand. Recently, METS was completely rewritten as a quantitative decision model within the software package Analytica and renamed eMETS. Dr Logan's presentation reviewed the strategy modelling method, its benefits and limitations and highlighted some recent simulation outputs.

The second seminar on the 27th April was presented by Adjust Professor Mike Regan, Chief Scientist – Human Factors, ARRB. Professor Regan spoke at length on driver distraction, outlining the complexities of the topic such as the definition of distraction, how to measure it, how to quantify its impacts, and how to transfer research knowledge into policy that saves lives.

Toward the end of 2016, the WA Chapter has been actively involved in the organisation of the 2017 Australasian Road Safety Conference to be held in Perth, Western Australia, 10th-12th October. The Chapter is pleased to be working with the National ACRS office and other inviting partners and co-hosts, namely Austroads, ARRB and the Curtin-Monash Accident Research Centre.

WA Chapter Secretary
Mr Peter Palamara

ACRS News

ROAD DEATHS & INJURIES RISING: TIME TO FUND ROAD SAFETY ELECTION PROMISES IN BUDGET TO SAVE LIVES AND REDUCE INJURIES

"Taking a national, aspirational leadership approach to road safety could save at least $55B by 2020, and save over 2,300 lives and 50,000 serious injuries over the current decade", reports the President of the Australasian College of Road Safety, Mr Lauchlan McIntosh AM, in today's ACRS 2017-18 pre-Budget Submission.

The nation experienced a 7.9% increase in road deaths during 2016 compared to 2015, and the Federal Government reports that serious injuries have increased every year since 2000, placing an extra and unnecessary burden on the economy.

"Australia's National Road Safety Strategy 2011-2020, supported by all levels of government, aims for a 30% reduction in deaths and serious injuries by 2020 - we are in reverse in our efforts to reach this target and urgently need the Coalition's funding re-allocation to turn this around", said Mr McIntosh.

The submission states that Australia has fallen behind in every major measure of road safety performance when compared to the OECD over the last decade, and recommends investing what is a relatively modest amount now to at least be back in the top 10 by the year 2020.

"An almost insignificant reallocation of the substantial roads infrastructure funding in the Federal Budget, for road safety coordination, would bring significant benefit", said Mr McIntosh. "The Federal Coalition released a strong policy in August 2013 to improve road safety, but many components remain unfunded. In this 2017-18 Budget it is time make funds available".

"Imagine if our current annual number of road casualties - 1,300 killed and over 37,000 seriously injured each year - were killed or injured by war, plane crashes, or an epidemic", Mr McIntosh said. "There would be a national outcry and a national budget immediately".

The Federal Government has a clear responsibility for coordination and leadership, and for funding roads and vehicle standards. When there was a country-wide crisis with over 3,500 road deaths per year in the 1970's, a national approach including appropriate funding was implemented to bring about coordinated action. This action resulted in a significant reduction in trauma rates. However, road deaths and injuries are now rising and, although there is a National Road Safety Strategy and Action Plan for road safety, strategic leadership and coordination activities remain largely underfunded.

"Road trauma costs are felt across the entire community, and while the transport sector may bear the infrastructure and enforcement costs, the health and social service sectors bear the ongoing costs. Benefits of reduced trauma flow through into improved national productivity, a reduction in health costs, and enhanced social well-being", said Mr McIntosh.

The Submission states that reintroducing a holistic systems approach from the Federal Government will make a significant difference, supporting increased scale and coordination to ensure long term results.

The College's submission is for $1.7 million per year over three years to assist in building collaboration and coordination across all stakeholders. The submission includes improving national communication networks, implementing a national road safety research framework, developing a coordinated focus on collecting and analysing injury data, encouraging the community to recognise economic and societal benefits of trauma reductions, rewarding best practice, and supporting increased international collaboration across all sectors.

Sources:

2017-2018 ACRS Pre-Budget Submission: http://acrs.org.au/wp-content/uploads/ACRS-Pre-budget-Submission-FINAL1.pdf

Coalition's Policy to Improve Road Safety: https://bitre.gov.au/publications/2016/is_076.aspx

Road Deaths Australia Monthly Bulletin - December 2016 BITRE: https://bitre.gov.au/publications/ongoing/rda/files/RDA_Dec_2016.pdf

Developing national road safety indicators for injury (BITRE): https://bitre.gov.au/publications/2016/is_076.aspx

Contacts:

Mr Lauchlan McIntosh AM, ACRS National President - Mobile: 0418 424 886

Ms Claire Howe, ACRS Executive Officer, ACRS - Mobile: 0402 418 123

ACRS 2016 SUBMISSION TO THE PRODUCTIVITY COMMISSION: INQUIRY INTO AUSTRALIA'S PRODUCTIVITY PERFORMANCE WITH RECOMMENDATIONS ON PRODUCTIVITY-ENHANCING REFORM

The Australian Government has asked the Productivity Commission to undertake a 12 month inquiry into Australia's productivity performance and provide recommendations on reform priorities. This inquiry will be the first in a regular series, undertaken at five-yearly intervals, to provide an overarching analysis of where Australia stands in terms of its productivity performance, and to develop and prioritise reform options to improve the wellbeing of Australians by supporting greater productivity growth.

The Commission is also required to:

- analyse Australia's productivity performance in both the market and non-market sectors, including an assessment of the settings for productive investment in human and physical capital and how they can be improved to lift productivity.
- examine the factors that may have affected productivity growth, including an assessment of the impact of major policy changes, if relevant.

The College prepared a submission for this inquiry as follows:

Summary

Australia's National Road Safety Strategy 2011-2020 sets out a range of strategies to reduce road trauma by 30% by the end of the decade, resulting in a reduction of the impost unnecessary road trauma impacts on national productivity. This Strategy is unfunded despite the national annual cost of road trauma being at least $32bn pa, 1.8% of GDP and increasing.

While such a reduction will have a positive benefit across many areas of the economy as evidenced in the *College submission to Parliamentarians in 2013* (to be updated early 2017) and in our submission in December 2013 to the *Productivity Commission Inquiry into Public Infrastructure*, Australia has fallen behind that target, are falling behind when we make international comparisons and have a limited strategic approach to assess the problem, and doubt whether we fully understand the complete national economic losses associated with road trauma.

All Federal funding for road infrastructure should be conditional on safety outcomes.

Federal standards for new vehicles should actively encourage best practice collision avoidance technologies.

International research suggests that real progress in reducing road trauma will necessitate a fundamental paradigm shift in the way the road safety problem is viewed, as well as the strategies used to address it. As a result, a national strategy program to reflect that paradigm shift must be initiated.

Recommendations:

- Recognises the full impacts of road trauma on the national economy;
- Recognises the lack of national accounting for the full impacts of road trauma on the national economy; and
- Recognises the value of a significant national investment in road safety strategic oversight, research and development to ensure we build the scale required to reduce the impact and cost of road trauma in the future.

Read the Complete ACRS 2016 Submission (http://acrs.org.au/wp-content/uploads/ACRS-Inquiry-into-Austr`alias-Productivity-Performance-FINAL.pdf), and visit the Productivity Commission's Website (http://www.pc.gov.au/inquiries/current/productivity-review) for further information. The Commission is due to report on the Inquiry in September 2017.

NEWS FROM ACRS FELLOW, MR IAIN CAMERON: 'ZERO ROAD DEATHS' STUDY WINS INTERNATIONAL SAFETY AWARD

A new report setting out a radically new approach in road safety has won the 2017 Special Award of the prestigious Prince Michael of Kent International Road Safety Awards. The award-winning study by a group of 30 international road safety experts from 24 countries, convened by the International Transport Forum at the OECD, reviews the experiences of countries that have made it their long-term objective to eliminate fatal road crashes.

Originating in Sweden, this "Vision Zero" is not utopian, but demonstrably realistic:

- 88 European cities with a population above 100 000 have not had any road fatalities over the course of a whole year. The biggest among them are Nottingham in the UK (pop. 289 000), Aix-la-Chapelle (Aachen) in Germany (pop. 260 000) and Espoo in Finland (pop 259 000)
- 16 European towns above 50 000 inhabitants experienced no road deaths for five years running: 9 in the United Kingdom, 6 in Germany and one in Norway
- Not a single child died as result of a bicycle crash in Sweden in 2008
- Countries, cities and companies around the world are adopting zero road deaths as their aspiration:
- New York City launched an action plan in 2014 to eliminate road deaths
- Volvo Cars' objective is that no-one should be killed or injured in a new Volvo by 2020

Still, 1.25 million people are killed by traffic every year, according to the World Health Organization. Road crashes are the leading cause of death worldwide for young people aged 15 to 29. Traffic is the ninth leading cause of death overall, killing more people than malaria. 90% of road deaths occur in low-income countries, where rapid motorisaton drives up fatalities. In many developed countries, the progress made over the past decades has stalled.

The International Community has set itself the objective to halve global road deaths by 2020 in the UN Sustainable Development Goals. To make progress towards this ambitious goal require new thinking. The award-winning ITF report "Zero Road Deaths and Serious Injuries: Leading a Paradigm Shift in Road Safety" offers guidance for leaders that want to drastically reduce the road deaths in their communities and sets out how a "Safe System" approach to road safety can underpin this goal.

Congratulating ITF on the award, Prince Michael of Kent said: "The new report comes at a time when the world needs to change up a gear or two to accelerate efforts to reduce the unacceptable toll of death and serious injury on our roads. It is a most welcome addition to the all-important bank of knowledge available to governments and a fine example of the leadership shown by ITF."

José Viegas, Secretary-General of the International Transport Forum, said: "No-one should pay with their lives as the price for a mobile society. Road safety policy can do more than limit the collateral damage; it can make roads and vehicles fundamentally safe for all. In occupational safety, machinery and processes have long been conceived as a 'Safe System' built to avoid death and minimize injury in the first place. Our new report wants to entice countries and cities to embark on this journey and turn their road traffic into such a Safe System. This prestigious award is a fantastic encouragement for us."

Iain Cameron (FACRS - Fellow of the Australasian College of Road Safety), chairman of the ITF Working Group which prepared the report, said: "We must accept that people make mistakes in traffic if we are to stop the death and serious injury epidemic on our roads. We need a paradigm shift in the way we view and approach road safety policy, and we need it now. It is unrealistic to expect that education and enforcement alone will bring the needed step change. Even road users who know and follow the rules make mistakes. A Safe System creates an environment in which simple mistakes will no longer kill people."

The award-winning report highlights four principles for policy and design to achieve a Safe System:

- People make mistakes that lead to crashes.
- The human body has a known, limited ability to withstand impact forces.
- There is shared responsibility for safety among those who use, design, build, operate the system.
- All parts of the traffic system must be strengthened to multiply the protective effects and ensure that when one part fails the others will provide protection.

The report's core recommendations to policy makers and the road safety community are:

- Be ambitious - think safe roads, not just safer roads: The conventional approach to road safety seeks incremental improvements to current practice. A Safe System works backwards from the vision of zero road deaths and creates new perspectives on how to do it.
- Be resolute - foster a sense of urgency and lead the way: In communities that have adopted a Safe System, innovation occurred where political leaders strongly felt that the current approach no longer delivered. Nothing will change in road safety without strong leaders.
- Be inclusive - establish shared responsibility for road safety: Today, avoiding crashes is the responsibility of the road user. A Safe System requires everyone with a role in the traffic environment to recognize this role and assume responsibility for making traffic safe.
- Be concrete - underpin aspirational goals with concrete operational targets: Establishing milestones that are attainable for clearly defined groups or issues show that the overall vision of zero road deaths is long-term but realistic.

The Prince Michael International Road Safety Awards recognise achievement and innovation in road safety. Launched by Prince Michael in 1987, the awards are made to organisations and companies in recognition of their enormous contribution to reducing the toll of road death and injury across the world.

AUSTRALASIAN ROAD SAFETY CONFERENCE 2017 (ARSC2017) IS SHAPING UP TO BE ANOTHER FANTASTIC EVENT SUPPORTING ROAD TRAUMA REDUCTIONS

If you haven't seen Australia's spectacular West, this is the ARSC conference for you! The Australasian College of Road Safety (ACRS), Austroads, ARRB and Curtin Monash Accident Research Centre (C-MARC) invite you to attend the largest road safety-dedicated conference in the Southern Hemisphere. The 2017 Australasian Road Safety Conference (ARSC2017) will be held in Perth on the banks of the Swan River at the beautiful Crown complex from Tuesday to Thursday 10-12 October 2017.

With a theme of **"Expanding our horizons"**, ARSC2017 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: Road Safety Management; Infrastructure; Safe Vehicles; User Behaviour, and Post-Crash Care.

ARSC2017 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. The comprehensive 3-day scientific program will showcase the latest:

- Research;
- Education;
- Policing programs;
- Policies and management strategies;
- Technological developments in the field;
- National and international keynote speakers;
- Oral and poster presentations;
- Expansive stakeholder exhibition; and
- Workshops and interactive symposia.

ARSC2017 is expected to attract over 500 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.

Please join us in Perth in October 2017 to help us all to maintain this positivity and momentum – there is so much more that all of us are capable of, especially when we are working in a collaborative and supportive environment such as the one evident at ARSC2016. We look forward to seeing you in Perth!

Diary

March 9
RoSPA Road Safety Conference 2017
Birmingham, UK
http://www.rospa.com/events/road/

March 20-23
10th International Conference on Managing Fatigue
San Diego, USA
http://fatigueconference2017.com/

April 6-7
Traffic Management Association of Australia Annual Conference 2017
Gold Coast, Australia
http://www.tmaaconference.com.au/

May 21-24
5th International SaferRoads Conference
Auckland, New Zealand
http://saferroadsconference.com/

June 12-15
1st International Roadside Safety Conference
San Francisco, USA
http://onlinepubs.trb.org/onlinepubs/conferences/trb_irsc_call_for_abstracts.pdf

June 18-21
CARSP Conference 2017
Toronto, Canada
http://www.carsp.ca/carsp-conference/carsp-conference-2017/

October 10-12
Australasian Road Safety Conference 2017
Crown Perth, Australia
www.australasianroadsafetyconference.com.au

October 17-19
Road Safety & Simulation International Conference 2017
The Hague, Netherlands
http://rss2017.org/

Peer-reviewed papers

Original Road Safety Research

Decompartmentalising road safety barrier stiffness in the context of vehicle occupant risk

Andrew Burbridge[1,2] and Rod Troutbeck[3]

1Queensland Department of Transport and Main Roads, Brisbane, Australia, andrew.z.burbridge@tmr.qld.gov.au

2CARRS-Q, Queensland University of Technology, Brisbane, Australia, andrew.burbridge@hdr.qut.edu.au

3CARRS-Q, Queensland University of Technology, Brisbane, Australia, r.troutbeck@qut.edu.au

Corresponding Author: Andrew Burbridge, GPO Box 1412, Brisbane, QLD 4001, andrew.z.burbridge@tmr.qld.gov.au, (+61)7 3066 8016.

This peer-reviewed paper was first presented at the 2016 Australasian Road Safety Conference (ARSC2016) held in Canberra, ACT, Australia and first published in the ARSC2016 Proceedings as a 'Full Paper'. It underwent the full peer-review process by independent experts in the field and was subsequently short listed for a prize. 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

- Road safety barriers present a continuum of vehicle occupant risk.
- Such a continuum is a function of impact conditions and system flexibility.
- Conventional descriptors "rigid", "semi-rigid" and "flexible" may be inadequate.

Abstract

Road safety barriers are selected for deployment on the basis of four basic criteria; costs, deflection performance, containment capacity, and severity outcomes. System specific severity risk to occupants of errant vehicles is not well established. Contemporary technical governance in the Australian context recognises three generic barrier types discerned by relative stiffness: rigid, semi-rigid, and flexible. This study explores how the occupant severity indicator Acceleration Severity Index (ASI) varies as a function of impact configuration and system stiffness. This study demonstrates that systems available to road safety practitioners may be better served by a continuum rather than a generic classification system.

Keywords

Road safety barriers, Acceleration Severity Index

Introduction

Road safety barriers are selected for deployment on the basis of four basic criteria:

- Costs
- Deflection performance
- Containment capacity
- Severity outcomes

Information regarding device-specific deflections and containment capacity is readily available to practitioners. Reasonable estimates of capital, maintenance and repair costs for any system can be relatively easily established. However device specific severity risk to occupants of errant vehicles is less well established.

Contemporary technical governance in the Australian context recognises three generic barrier types, discerned by relative stiffness. According to the Guide to Road Design Part 6 (Austroads, 2009) road safety barriers are described as flexible, semi-rigid or rigid. Australian/New Zealand Standard AS/NZS 3845.1:2015 (Standards Australia, 2015) is complicit in this regard. By such definitions, the rigid classification includes concrete barriers and steel bridge rail barriers. Flexible barriers are typically wire rope (cable) barriers, while semi-rigid barriers include post-mounted steel rail systems. Thereafter, in terms of vehicle occupant severity Jurewicz et al (2014) provide Fatal and Serious Injury (FSI) ratios for each of these three generic road safety barrier types, albeit noting that the differences between values are "*not statistically significant*". Likewise, the Australian National Risk Assessment Model (ANRAM) (Jurewicz, Steinmetz, & Turner, 2014) provides risk factors for three generic barrier types, viz, 'concrete', 'metal' and 'wire rope'.

However the assumption that different barriers and the occupant risk they present can be placed into such discrete categories may be an over-simplification. Rather it may be appropriate to observe that barriers present a continuum of stiffness, and that occupant severity outcomes are as much a function of the stiffness of the barrier as the configuration of the impact.

This study is an exploration of how the occupant severity indicator Acceleration Severity Index (ASI) measured during crash testing might be expected to vary as a function of barrier stiffness and the configuration of the impact.

Background

Road safety barriers deployed by Australian road authorities are homologated against established test protocols that prescribe the requirements for full-scale crash testing. Such testing is a function of both the test vehicle in terms of mass and shape, and the impact conditions: speed and angle of incidence. Australian/New Zealand Standard AS/NZS 3845.1:2015 (Standards Australia, 2015) nominates the Manual for Assessing Safety Hardware (MASH) (AASHTO, 2009) as the preferred test protocol for the homologation of road safety barriers. MASH provides that a road safety barrier intended for the containment of light passenger vehicles (i.e., cars) is tested using a 2270 kg pick-up (a utility) and an 1100 kg small car. The larger vehicle test is a test of the capacity of the barrier, while the smaller vehicle test is intended to show that the road safety barrier does not present undue risk to the occupants of smaller/lighter vehicles.

Since a light vehicle is used to test for occupant risk, it is reasonable to expect that a slightly heavier vehicle would present a lower level of occupant risk, and that (notwithstanding other confounding factors such as vehicle age and vehicle safety rating) for the same impact conditions a continuum of occupant risk would exist as a function of vehicle mass. Further, it is reasonable to expect that occupant risk is a function of the Impact Severity, or kinetic energy of the impact. And since speed and angle are components of Impact Severity, occupant risk is also a function of speed and angle of impact. This is supported variously throughout published literature.

For example, Monash University conducted a series of crash tests using identical vehicles to impact three barrier systems (F-shape concrete (rigid), U-section post guardrail with 2.5 m post-spacings (semi-rigid) and an unidentified proprietary wire rope system with 2.5 m post-spacings and unspecified rope tension (flexible)) each at 80 km/h and 45 degrees and at 110 km/h at 20 degrees (Corben et al., 2000; Grzebieta et al., 2002). Ydenius et al. (2001) report that impact with the concrete barrier at 80 km/h and 45 degrees was the most severe impact configuration in terms of all metrics employed, but that "*at slight impact angles (< 20°) the perpendicular forces on the barrier are relatively small, which most likely leads to a moderate vehicle crash severity*".

Similarly, Hammonds and Troutbeck (2012) report on parametric comparison testing of three barrier systems (F-shape concrete (rigid), C-section post guardrail with 2.0 m post-spacings (semi-rigid) and an unidentified proprietary wire rope system with 2.5 m post-spacings and rope tension 20 kN (flexible)). Each barrier type was subjected to impact at 100 km/h and 20 degrees by four vehicles: an 1100 kg small car (Daihatsu Charade), an 1850 kg intermediate car (Holden Commodore), a 2500 kg larger passenger car (Toyota Landcruiser), and an 8000 kg single unit truck (Mitsubishi). Hammonds and Troutbeck report (among other things) that "*when designing for reduced occupant injury, there is little practical difference between wire rope and W-Beam*", but that the occupant severity indicators measured during impacts with the concrete barrier, while more severe than for the other two barrier types, were still within acceptable limits, and "*well below those recorded in the ANCAP tests*". Importantly, in the context of this study, Hammonds and Troutbeck propose that for non-rigid systems, "*the 'apparent' stiffness of the barrier is affected by the mass of the impacting vehicle and the manner in which it interacts with the barrier*" (Hammonds & Troutbeck, 2012).

Michie et al (1971) observe that in terms of lateral acceleration, a rigid barrier was found to perform favourably when compared to semi-rigid systems in shallow angle (less than 15 degrees) impacts, and that in operator-driven tests where the barrier was repeatedly struck at 50 mph at 8 degrees "*no vehicle damage or driver injuries were observed*". The authors caution however that in large angle (> 20°) impacts, vehicle redirection is "*abrupt*". This is consistent with Bronstad et al (1987) who report on the evaluation of an array of longitudinal road safety barriers tested against the provisions of the US test protocol NCHRP Report 230 (Michie, 1981), finding that 15 degree impacts are not a discerning test for occupant risk, but that 20 degree impacts are a discerning test. Consistent with Ydenius et al (2001), Michie et al (1971) find that vehicle mass is "*a most important parameter*", and that lighter vehicles are likely to experience more severe redirection.

The intent of this study is to explore how one particular occupant severity indicator measured during crash testing is observed to vary as a function of the conditions of impact and barrier stiffness.

Acceleration Severity Index

Acceleration Severity Index (ASI) is a non-dimensional occupant severity indicator calculated from orthogonal time-averaged time-acceleration traces measured during crash testing at the centre of mass of the impacting vehicle. ASI is calculated according to the expression in Equation 1:

$$ASI = max\left[\left(\frac{a_x}{\hat{a}_x}\right)^2 + \left(\frac{a_y}{\hat{a}_y}\right)^2 + \left(\frac{a_z}{\hat{a}_z}\right)^2\right]^{\frac{1}{2}} \qquad \text{Equation 1}$$

where are average component vehicle accelerations respectively in the longitudinal, lateral and vertical direction measured over a prescribed time interval (50 milliseconds), and are corresponding threshold values for the respective component accelerations (Gabauer & Gabler, 2005). The denominator values for the component threshold accelerations as adopted in both the US and European test protocols are respectively g, g and g (and g = acceleration due to gravity). These threshold values are consistent with those presented by Weaver et al (1975) for lap-belted occupants, and are notably equivalent to approximately 60% of the threshold values proposed for the lap and shoulder belt restraint condition. ASI is a mandatory measure under the European test protocol EN1317-1/EN1317-2 (European Committee for Standardization, 2010a, 2010b) which use ASI (among other things) to classify barriers according to occupant severity. ASI is also required to be measured under Australian/New Zealand Standard AS/NZS 3845.1:2015 (Standards Australia, 2015), but there are no mandatory performance criteria.

Objectives

In summary, it is reasonable to hypothesise that occupant severity indicator ASI may be expected to increase as a function of:

- Decreasing vehicle mass;
- Increasing impact speed;
- Increasing impact angle;
- Increasing barrier stiffness.

The aim of this study is to present an argument that:

1. generic road safety barrier types cannot be categorised generically, but comprise a continuum of solutions in terms of barrier stiffness, and,
2. occupant injury risk as a function of barrier stiffness is similarly a continuum, and a function of the configuration (mass, speed and angle) of the impacting vehicle.

The objective of this study is to present a graphical analysis of the results of full scale crash testing to demonstrate that both occupant risk indicator ASI results and barrier stiffness are represented by a continuum and are not categorical.

Methodology

Vehicle mass, impact speed, impact angle, dynamic deflection and ASI are each recorded for 63 road safety barrier hardware crash tests sourced (mainly) from the FHWA website (US Department of Transportation Federal Highway Administration) supplemented with a small amount of other limited literature obtained generally from the public domain. This data is tabulated in Table 1. Impact severity for each impact is calculated in accordance with the expression at Equation 2 (Sicking & Ross Jr, 1986), and is measured in terms of energy.

$$IS = {}^1/_2\, m(v.\sin\theta)^2 \qquad \text{Equation 2}$$

where

IS = Impact Severity (kJ)
m = mass (t)
v = vehicle speed (m/s)
θ = angle of incidence (degrees)

In terms of road safety barrier characteristics, the term ‘stiffness’ represents resistance to deformation, which is also the decelerating force imposed on an impacting vehicle. And since energy is the product of force and distance, so barrier stiffness (as resistive force) is energy per unit of displacement. However, because rigid barriers by definition exhibit practically zero dynamic deflection and hence effectively an infinite stiffness which is inconvenient in calculation, the term ‘flexibility’ is coined here as the reciprocal of ‘stiffness’. For the purpose of this study, barrier ‘flexibility’ is calculated in accordance with the expression at Equation 3.

$$Flexibility = \frac{DD}{IS} \qquad \text{Equation 3}$$

where DD is dynamic deflection (m). Hence, ASI can be plotted against ‘flexibility’ for all 63 records.

Firstly, the data is disaggregated by generic barrier type, according to the following classifications:

- Bridge rail (BR);
- Transitions (TR);
- Strong Post W-Beam (SPWB);
- Thrie-beam (TB);
- Weak Post (WPWB);
- Wire rope (WR).

Secondly, the data is disaggregated according to the nominal configuration (mass, speed, angle) of the crash test. Three nominal crash test configurations (NCHRP Report 350 (Ross et al., 1993) and MASH (AASHTO, 2009) tests 3-10, 3-11 and 4-12) dominate the impact conditions in the data set. For the sake of this study, transition tests designated 3-21 and 4-22 are considered equivalent in terms of configuration to 3-11 and 4-12 tests respectively. Descriptive data of 60 of the 63 tests (three 1100 kg MASH 3-10 tests are omitted) are provided in Table 2.

Table 1. Crash test data (63 crash tests)

Type	Test ref.	Nominal test configuration	Mass	Speed	Angle	Dynamic deflection	ASI	Source[a]
BR	421323-1	4-12	8009	81.40	14.3	0.000	0.56	(Footnote[b])
BR	421323-2	3-11	2063	98.30	26.4	0.000	1.86	(Footnote[b])
BR	TTI 404251-2	3-11	2000	99.40	25.4	0.000	1.70	FHWA b066
BR	TTI 404251-3	4-12	8000	79.60	14.9	0.010	0.50	FHWA b066
BR	TTI 404311-1	3-10	820	100.00	20.8	0.000	1.80	FHWA b055
BR	TTI 404311-2	3-11	2000	100.70	25.8	0.040	1.66	FHWA b055
BR	TTI 404311-3	4-12	8000	78.70	14.9	0.005	0.51	FHWA b055
BR	418049-7	3-11	2000	101.40	24.8	0.005	1.50	FHWA b224
BR	400001-SCW1	3-11	2000	101.60	25.2	0.000	1.60	FHWA b073
TR	404211-12	3-21	2000	101.30	24.2	0.070	1.85	FHWA B065
TR	404211-9	3-21	2000	100.80	25.6	0.077	1.68	FHWA B077
TR	TTI 401181-1	4-21	2135	102.30	24.9	0.200	1.74	FHWA b146
TR	TTI 401181-2	4-21	2108	96.90	25.2	0.060	1.73	FHWA b146
TR	TTI 401181-3	4-22	8106	80.80	13.6	0.180	0.34	FHWA b146
SPWB	400001-CF11	3-11	2000	101.40	26.3	0.811	0.81	FHWA b080
SPWB	471470-26	3-11	2000	100.80	24.3	0.820	0.95	(Footnote[c])
SPWB	41-1655-001	3-11	1992	100.40	25.0	1.300	0.90	FHWA b080a
SPWB	41-1655-002	3-10	816	101.80	20.0	0.500	1.10	FHWA b080a
SPWB	53-0017-001	3-11	1995	99.70	25.0	0.900	0.70	FHWA b109b
SPWB	MGSNB-1	3-11	2273	100.90	24.7	0.867	0.86	(Footnote[d])
SPWB	MGSNB-2	3-10	1092[e]	101.40	25.5	0.740	0.97	(Footnote[d])
TB	220570-5	3-10	877	102.60	19.8	0.340	1.26	FHWA b148
TB	220570-6	4-12	8192	78.80	15.3	0.810	0.26	FHWA b148
TB	220570-7	3-11	2290	99.00	24.5	0.630	1.43	FHWA b148
WPWB	-	3-10	906[f]	101.70	20.0	1.020	0.63	FHWA b229
WPWB	-	3-11	2258	99.70	25.0	1.670	0.58	FHWA b229
WPWB	220570-4	3-11	825	102.10	20.3	0.490	1.05	FHWA b140
WPWB	57073101	3-10	837	102.20	20.3	0.680	0.66	FHWA b162
WPWB	57073112	3-11	2233	98.00	24.5	1.050	0.59	FHWA b162
WPWB	5707b3111	3-11	2053	100.50	24.5	1.150	0.56	FHWA b162
WPWB	570734121	4-12	8050	78.30	15.0	1.220	0.22	FHWA b162b
WPWB	102350.97.05.1.5.2	3-10	1110[e]	100.80	25.0	0.960	0.73	FHWA b229
WPWB	102350.97.05.1.5.1	3-11	2273	99.00	25.0	1.280	0.58	FHWA b229
WR	MIRA-99-436009	3-11	1999	99.40	26.0	2.400	0.36	FHWA b082[g]
WR	MIRA-99-436008	3-10	898	101.00	20.0	1.040	0.55	FHWA b082[g]
WR	400001-MSC2	3-11	2040	100.70	25.3	1.990	0.60	FHWA b096
WR	400001-TCR1	3-11	2045	100.60	24.2	2.400	0.37	FHWA b119
WR	400001-TCR2	3-11	2050	99.40	25.7	2.800	0.36	FHWA b119a
WR	MIRA-05-D0002	3-10	807	100.80	21.3	1.350	0.55	FHWA b082b
WR	400001-SFR4	3-11	2074	99.30	25.7	1.800	0.49	FHWA b096a
WR	-	3-10	827	100.20	20.0	0.762	0.66	FHWA b137

Type	Test ref.	Nominal test configuration	Mass	Speed	Angle	Dynamic deflection	ASI	Source[a]
WR	-	3-11	2065	102.40	25.0	2.620	0.33	FHWA b137
WR	400001-TCR8	3-11	2106	96.50	24.7	2.360	0.45	FHWA b141
WR	400001-SFR5	3-11	2123	98.10	26.4	2.310	0.42	FHWA b096a
WR	400001-TCR9	4-12	8196	82.50	14.1	2.205	0.14	FHWA b141
WR	MIRA-05-c0050	4-12	8050	79.70	15.8	2.210	0.18	FHWA b082b
WR	TR-P26021-01-A	3-11	2020	99.85	25.0	2.000	0.44	FHWA b137b
WR	TR-P26028-01-B	3-11	2020	101.50	25.0	2.800	0.44	FHWA b137b
WR	400001-TCR12	3-11	2102	102.60	24.9	3.410	0.40	FHWA b141b
WR	P26133-01	3-10	812	97.51	25.0	1.500	0.84	FHWA b137c
WR	P26133-03	3-11	2222	97.05	25.0	2.610	0.35	FHWA b137c
WR	P26133-04	3-10	845	101.63	20.0	1.430	0.63	FHWA b137c
WR	570723102	3-10	829	100.50	20.1	1.400	0.54	FHWA b167
WR	50724121	4-12	8050	84.50	15.0	2.290	0.15	FHWA b167
WR	570723118	3-11	2080	99.50	25.0	2.550	0.46	FHWA b184a
WR	400001-NSM10	3-11	2313	101.71	26.6	2.926	0.40	FHWA b193rev
WR	400001-NSM11	3-10	816	99.50	21.4	0.985	0.50	FHWA b193rev
WR	405160-11-1	3-11	2051	100.26	25.4	3.109	0.67	FHWA b227
WR	102350.02-6-311	3-11	2044	97.60	25.0	1.540	0.44	FHWA b222
WR	102350.02-6-412	4-12	8050	82.50	15.0	1.650	0.17	FHWA b222
WR	102350.02-6 T3	3-10	834.5	99.70	20.0	1.280	0.60	FHWA b222
WR	400001-TCR40	3-11	2288	100.58	25.8	2.926	0.36	FHWA b232
WR	400001-TCR41	3-10	1091[e]	74.35	26.1	2.286	0.72	FHWA b232

Footnotes

a. All FHWA references are sourced from FHWA website (US Department of Transportation Federal Highway Administration)

b. Alberson et al (2004)

c. Mak et al (1999) / Plaxico et al (2000)

d. Reid et al (2013)

e. MASH 3-10 tests employ a nominal 1100 kg vehicle impacting at a nominal 25 degree angle.

f. 906 kg is recorded as a gross test vehicle weight, rather than a test inertial weight.

g. MIRA test reports referenced in FHWA letter b082 made available by Queensland Department of Transport and Main Roads.

Table 2. Combined descriptive data for 60 of 63 crash tests (MASH 3-10 tests omitted)

Nominal crash test	Mass (kg)		Speed (km/h)		Angle (degrees)		Count
	Nominal	Range	Nominal	Range	Nominal	Range	
3-10	820	807 - 906	100	97.5 - 102.6	20	19.8 - 25.0	14
3-11	2000	1992 - 2313	100	96.5 - 102.6	25	24.2 - 26.6	36
4-12	8000	8000 - 8196	80	78.3 - 84.5	15	13.6 - 15.8	10

Limitations

Firstly, the study takes the crash test data at face value as is presented in the crash test summary sheets. For example, it may be that some of the mass/speed/angle data is reported as nominal values rather than accurately recorded.

Secondly, it is observed that the European and US methods for calculating ASI are subtly different (Naish & Burbridge, 2015). Further, Anghileri (2003) reports on variations in reported ASI from round-robin testing of ASI conducted at six European laboratories, suggesting that variations in both the tests themselves and the process of evaluation may be responsible for some variation in calculated/reported ASI value.

Results

The results of plotting ASI against 'flexibility' are depicted in Figure 1. Figure 2 depicts the same data disaggregated respectively according to the six generic barrier classifications nominated above. Figure 3 depicts the same data (with three records removed) disaggregated according to the configuration of the common nominal impact conditions (in terms of mass, speed and angle) adopted in the respective crash test.

With regard to Figure 1 and Table 3 it is apparent that the range of ASI values is broadest where the flexibility is zero (i.e., the barrier is most stiff). At the y-axis, ASI values range from 0.50 to 1.86. However, the spread of data generally diminishes as barrier flexibility increases.

Moreover, there is a diminution in the ASI values recorded as the impacted systems become less stiff. Figure 2 and Table 3 indicate (as should be expected) that there is a stiffness hierarchy in terms of barrier classification, ranging from bridge rail (stiffest) to wire rope (least stiff). And generally, the wire rope returns the lowest values of occupant risk indicator ASI, while bridge rail returns the highest values. Figure 3 indicates that increase in barrier flexibility is associated with a decrease in recorded ASI value for each of the three crash test configurations.

Most obviously there are three distinct bands of results. The ASI value for the nominal 8000 kg, 80 km/h, 15 degree tests clearly represent the lower bound of the results, whereas the results from the nominal 800 kg, 100 km/h, 20 degree tests generally represent the upper bound. Also notably, the results from the nominal 2000 kg, 100 km/h, 25 degree tests are generally sandwiched between the results from the two other test configurations, but it is evident that as barrier flexibility approaches zero (near to the y-axis) the ASI results from this test configuration appear to rise sharply.

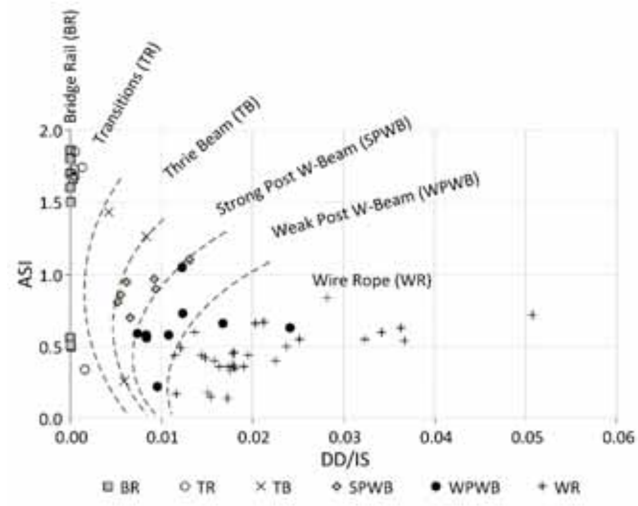

Figure 1. ASI v Flexibility (Dynamic Deflection/Impact Severity) for results from 63 crash tests

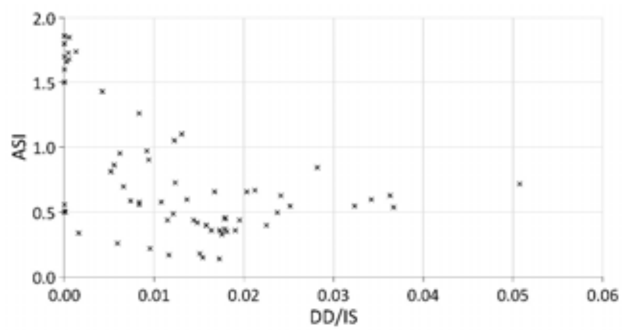

Figure 2. ASI v Flexibility (Dynamic Deflection/Impact Severity) for results from 63 crash tests disaggregated according to generic barrier classification

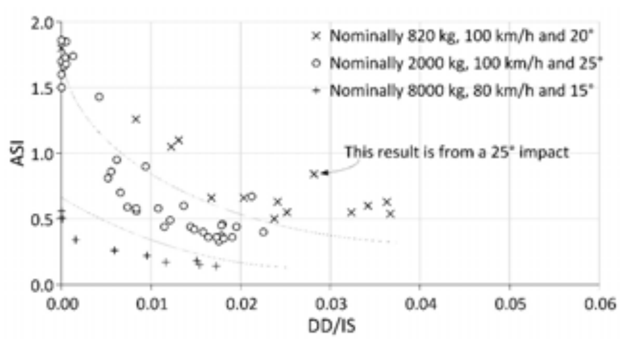

Figure 3. ASI v Flexibility (Dynamic Deflection/Impact Severity) for results from 60 crash tests disaggregated according to configuration of nominal impact conditions (mass, speed and angle)

Table 3. Summary of ASI results disaggregated by generic barrier type

	BR	TR	TB	SPWB	WPWB	WR
Max	1.86	1.85	1.43	1.10	1.05	0.84
Min	0.50	0.34	0.26	0.70	0.22	0.14
Count	9	5	3	7	9	30

Discussion

The results from all of the crash tests depicted in Figure 1 suggest that there may be a relationship between barrier flexibility and the ASI value recorded during crash testing, and moreover that ASI appears to be inversely proportional to barrier flexibility, perhaps represented by an exponential form. The results as depicted in Figure 3 reiterate this notion, but also suggest that the shape of the relationship curve is a function of the configuration of the impact. The results for the nominal 8000 kg, 80 km/h, 15 degree tests for example indicate a distinct decay curve, as do the results from the two other nominal crash test configurations. The following observations are apparent:

- ASI is highest for the lightest (kg) vehicle impacts (typically 100 km/h and 20 degrees).
- ASI is lowest for the heaviest (kg) vehicle impacts (typically 80 km/h and 15 degrees).

Notably the lowest values of ASI are also returned from impacts with the lowest impact speeds and highest for the highest impact speeds. Also, the effect of the flexibility (or stiffness) of the barrier is evident in the shape of the curve for each impact configuration. This is consistent with Anghileri, Luminari and Williams (2005) who report a "*weak correlation between … ASI and dynamic deflection*". In this regard, the following observations are suggested from the data:

- The shape of the ASI-flexibility curve is flattest for the lowest angle impact (15 degrees).
- The shape of the ASI-flexibility curve is steepest for the highest angle impact (25 degrees).

Together, these findings are consistent with the hypothesis proposed earlier that ASI may be expected to increase as a function of decreasing vehicle mass, increasing impact speed, increasing impact angle, and increasing barrier stiffness. Moreover, it is observed that the spread of occupant severity outcomes associated with more flexible systems is much narrower than the spread of occupant severity outcomes associated with stiffer systems, suggesting that occupant outcomes from impacts with more flexible systems are less susceptible to variation in the impact conditions than are occupant outcomes from impacts with stiffer systems. Further analysis of the effect of vehicle mass, impact speed, impact angle and barrier stiffness on the value of the occupant risk indicator is likely to be the subject of future work.

Apparent from Figure 2 is that barrier classifications are not fully discrete, but rather suggest some degree of overlap between systems. In the context of "*decompartmentalising road safety barrier stiffness*" the data suggests for example that weak post w-beam systems are likely to be more forgiving in terms of occupant injury than are strong post systems. Hence it is arguable that it is inappropriate to represent the spectrum of steel beam systems within a single barrier classification. At the other end of the steel beam spectrum, the data suggests that thrie beam and transition systems are generally less flexible than strong post w-beam systems and return higher values for the occupant risk indicator ASI. Since these are also steel beam systems, the point that it is inappropriate to represent the spectrum of systems within a single barrier classification is reiterated by the data. Indeed, it is arguable that combined, the suite of barrier solutions are better described by a continuum than the three generic barrier types 'concrete', 'metal' and 'wire rope'.

The results also suggest then that it would be appropriate in empirical studies of in-service performance to report the detail of the barrier in terms of the factors that might be expected to influence stiffness (for example post spacing, post type, rope configuration and tension).

Moreover, the results suggest that more specific detail about the impact configuration contributing to a given occupant outcome is necessary to make objective observations about the aggressiveness of any system.

Conclusions

The objective of this study was to present a graphical analysis of the results of full scale crash testing to demonstrate that both occupant risk indicator ASI results and barrier stiffness are represented by a continuum and are not categorical. This is achieved in Figure 2. The study has demonstrated that occupant risk measured in terms of ASI is likely to be a function of the speed, mass and angle of the impact as well as the stiffness of the system. The results suggest that it would be appropriate in empirical studies of in-service performance to report the detail of the barrier in terms of the factors that might be expected to influence stiffness of the system (for example post spacing, post type, rope configuration and tension) as well as the configuration of the impact (vehicle mass, impact speed and impact angle).

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An estimate of the future road safety benefits of autonomous emergency braking and vehicle-to-vehicle communication technologies

Jeffrey K Dutschke[1], Daniel J Searson[2], Giulio Ponte[3], T Paul Hutchinson[4], Robert W G Anderson[5] and Mary Lydon[6]

1 Centre for Automotive Safety Research, The University of Adelaide, Adelaide, Australia, jeff@casr.adelaide.edu.au

2 Centre for Automotive Safety Research, The University of Adelaide, Adelaide, Australia, daniel@casr.adelaide.edu.au

3 Centre for Automotive Safety Research, The University of Adelaide, Adelaide, Australia, giulio@casr.adelaide.edu.au

4 Centre for Automotive Safety Research, The University of Adelaide, Adelaide, Australia, paul@casr.adelaide.edu.au

5 Centre for Automotive Safety Research, The University of Adelaide, Adelaide, Australia,

and Hall Technical Pty. Ltd., Adelaide, Australia, rob@halltechnical.com.au

6 Centre for Automotive Safety Research, The University of Adelaide, Adelaide, Australia, mary@casr.adelaide.edu.au

Corresponding Author: Jeffrey Dutschke, Centre for Automotive Safety Research, The University of Adelaide, Adelaide, Australia, jeff@casr.adelaide.edu.au, +61 (0) 8 8313 5997

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Key Findings

- Autonomous emergency braking and vehicle-to-vehicle communication technologies has the potential to prevent a substantial number of both injury and fatal crashes.
- The full benefits of these technologies will only be realised when a substantial fraction of the Australian vehicle fleet has them installed.
- A faster rate of introduction of these technologies into new vehicles will prevent more crashes over many years, than a slower rate of introduction. Any mechanism that hastens the uptake of these technologies should be considered to improve road safety.

Abstract

The aim of this study was to examine the benefits of hastening the introduction of new passenger vehicle technologies on future reductions in fatalities and serious injuries on Australian roads. This was done specifically for Autonomous Emergency Braking (AEB) and Vehicle-to-Vehicle (V2V) communications, which represent the two most promising technologies in the short-term and medium-term future. The results demonstrate that a delay in introduction, or a slower rate of introduction, can have a substantial effect on how long it takes for the safety benefits to be realised in the greater vehicle fleet.

Keywords

Autonomous Emergency Braking (AEB); Vehicle-to-Vehicle (V2V) communication; Safety performance; modelling; technology introduction rate; crash reduction

Background

Autonomous Emergency Braking (AEB) in Australia, is a relatively new technology whereby forward facing sensors continually monitor the road ahead and are used to detect when a collision with another road user in its path is probable. When a forward collision is likely, the vehicle provides the driver with an initial warning to react, and subsequently, in the absence of any driver reaction applies a significant braking force to reduce the vehicle's speed. In an optimal situation the crash is avoided entirely, however even if the crash is unavoidable, the impact speed may be reduced thereby reducing the crash injury severity.

In Searson, Ponte, Hutchinson, Anderson and Lydon (2014), AEB was identified by every interviewed vehicle safety expert as being likely to have a significant road safety benefit in Australia over the next five to ten years. The literature has predicted that the benefits of AEB are potentially large using reconstruction and simulation techniques. Fildes et al. (2015) surveyed the literature for predicted benefits and showed estimates ranging between 4.3% and 44.0% crash reductions (for a range of impact scenarios including pedestrians). Fildes et al. (2015) also demonstrated an on-road reduction in rear-end low-speed crashes of 38% (confidence interval 18% - 53%), thereby verifying the potential magnitude of these estimates. Individual manufacturers have their own proprietary AEB systems and these act in according to their own algorithms, and at different maximum speeds (Hulshof, Knight, Edwards, Avery & Grover, 2013). Some operate as low speed AEB to avoid crashes in city traffic, while others can operate at high speed and may prevent crashes at highway speeds. The actual AEB effectiveness of an individual car is dependent on the specifics of the installed AEB system.

Vehicle-to-Vehicle (V2V) communications is another relatively new technology where vehicles communicate with each other via dedicated short-range communication devices (DSRC). If they are reporting their position, speed and direction to each other, then each will be able to determine if a crash between them is likely. If a crash is imminent the vehicle could take evasive action, including application of the brakes to avoid the crash occurring.

Searson et al. (2014) also found that V2V is a technology that interviewed experts believe may have a significant effect in the longer-term future. Although there are no results from long term trials that confirm this, research is promising and it is likely that V2V may fill the 'gaps' left by AEB by providing emergency braking that avoids or mitigates crashes. Doecke, Grant and Anderson (2015) showed that V2V communications could have a substantial reduction in crash occurrence of more than 90% under a range of crash configurations.

The rate at which each of these technologies is introduced into the vehicle fleet will be influenced by various factors. Among these is that they could be pushed into the market by government intervention, or they could be pulled by consumer demand. Government, through its design rules, potentially has the most power to encourage these technologies to be implemented quickly. Relying on individual consumers to voluntarily purchase for their own technology is possibly the slowest method of introducing the technology. More recently however, strong consumer advocacy groups such as the Australasian New Car Assessment Program have had the ability to encourage various technologies by rating cars as safer if they are equipped with this technology, and subsequently marketing the safety ratings to both fleet buyers and consumers. The speed that the technology is introduced is, however, an important factor in how effective it will be in the short and medium terms, regardless of the push and pull factors that are responsible for encouraging its introduction.

Searson et al. (2014) demonstrated that an aggressive approach to introducing these technologies into the Australian car fleet would see their benefits realised faster than a slower approach to their introduction. This paper updates that analysis to include the current rates of fitment of AEB technology.

This paper is not an analysis of the effectiveness of these technologies; it is, however, an analysis of the speed of introduction of these technologies. To achieve this aim, three different introduction rates are considered:

- an aggressive approach – possibly reflecting a design rule demanding that the technology is implemented;
- an encouraged approach – possibly reflecting a consumer organization marketing the benefits of the technology and rewarding vehicles using the technology with higher ratings; and
- a slow approach – possibly reflecting an adoption of the technology driven by individual consumers, without encouragement.

The timeframes adopted to model the effects of these different introduction rates (described in detail below) reflect the thoughts of the experts surveyed by Searson et al. (2014) about their potential availability in the market.

Method

AEB and V2V fitment rates

To model future fitment rates of the technology into new vehicles entering the fleet, a normal cumulative distribution curve was used. To define this curve, two endpoints were defined: an introduction year and a saturation year. The introduction year was the latest year in which less than 4% of new vehicles had the technology fitted. The saturation year was the latest year when less than 4% of new vehicles did not have the technology fitted. For the normal cumulative distributions, the mean was taken as the average of the introduction year and the saturation year and the standard deviation was one fifth of the time from the introduction year to the saturation year.

For the fitment of AEB, the saturation year for the aggressive introduction scenario, encouraged introduction scenario and the slow introduction scenario is 2020, 2025 and 2030, respectively. For AEB, there is already some introduction of this technology in the current Australian fleet. The rates of fitment of AEB from 2010 to 2015 are known for standard (not optional) new vehicle sales in the March to June quarter of each year (R. L. Polk Australia Pty Ltd, 2010-2015) and these are shown in Table 1. The breakdown of the operating capabilities of these AEB systems is not known. For the purposes of fitting the normal cumulative distribution curve, the introduction year in each introduction scenario was iteratively selected so that the fitment rate in 2015 was equal to 9.6% of vehicles in 2015, this being the actual percentage of vehicles fitted with AEB according to the data.

Table 1. Actual AEB Fitment rates (standard fitment) (R. L. Polk Australia Pty Ltd, 2010-2015)

Year	2010	2011	2012	2013	2014	2015
Actual AEB installation % (March to June Quarter)	1.5%	1.7%	2.2%	3.8%	6.6%	9.6%

It is also assumed that V2V technology will be introduced at a fitment rate that follows a normal cumulative distribution. The introduction year (less than 4% of all new vehicles fitted with V2V technology) for each of the scenarios is set to be 2020. The year of saturation (96%) of all vehicles fitted for the aggressive introduction scenario, encouraged introduction scenario and the slow introduction scenario is 2030, 2035 and 2045, respectively.

The rates of new car fitment, along with the percentage of vehicles fitted with the technologies is shown in Figure 1. The aggressive introduction curve is quite similar in shape to the electronic stability control introduction curve (ESC) in Gargett et al. (2011), although due to regulation for ESC occurring very quickly, early ESC prevalence was quite high. The initial and saturation years for the fitment rates are shown in Table 2.

Table 2. Curve fitting parameters used for future fitment rates

Introduction Scenario	AEB		V2V	
	Initial year*	**Saturation year**	**Initial year**	**Saturation year**
Aggressive	2014.25	2020	2020	2030
Encouraged	2013.50	2025	2020	2035
Slow	2012.73	2030	2020	2045
*Initial year for AEB was selected iteratively to closely match 9.6% fitment in 2015				

AEB and V2V effectiveness

The effectiveness of AEB and V2V technologies will be assumed to be as is reported in the literature. As discussed previously, this paper is not about the effectiveness of the AEB and V2V technologies but an analysis of the effect of introduction of these technologies, and the consequences of different introduction rates. Consequently, the choice of effectiveness value although important, is an adjustable parameter. As discussed in the background section, there are a range of effectiveness values that can be applied to AEB and V2V technologies. Some of these have been derived using simulation and reconstruction, others after investigating the effectiveness of technologies in the market.

For AEB effectiveness, Fildes et al (2015) reported an effectiveness of AEB of 38% in on-road low speed read end crashes. Lower values of effectiveness will be used in this analyses: 34% for injury crashes and 28% for fatal crashes, effectiveness values predicted from reconstruction by Anderson et al (2012) which includes additional crash types, and differentiates between fatal and injury crashes. For V2V effectiveness, Doecke and Anderson (2014) reported the marginal benefits of V2V as 16.0% for injury crashes and 11.9% for fatal crashes over and above the effectiveness of AEB (using their conservative 'restricted view' connected system). In this paper, the effectiveness of

AEB is defined collectively over the entire fleet, ignoring the capabilities of individual installed systems.

The benefits accrued due to AEB are assumed to be proportional to the percentage of total vehicles with the technology installed. This is because AEB can be effective even when only installed in one vehicle involved in a crash.

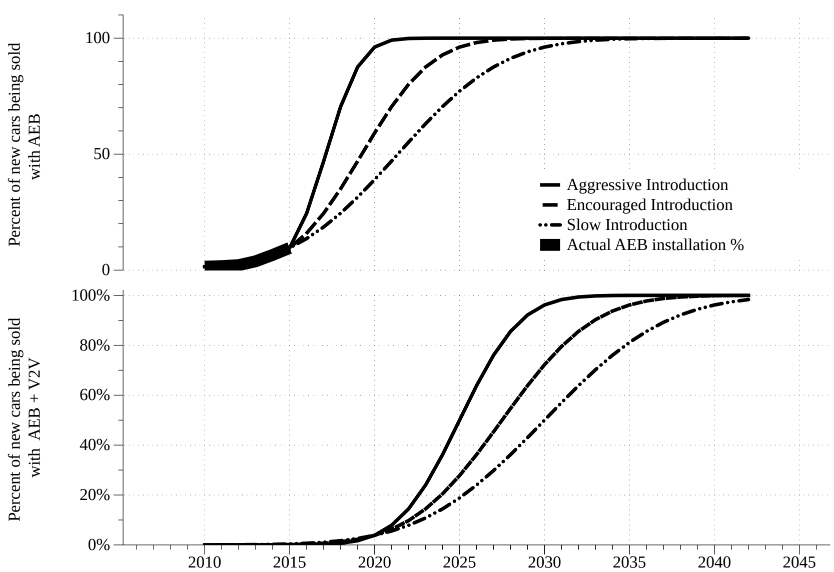

Figure 1. Actual and assumed fitment rates of AEB and AEB+V2V in Australian fleet projected until 2042

The benefits accrued due to V2V however, are assumed to be proportional to the square of the percentage of total vehicles with that technology installed. This is because both vehicles in a two car collision require the technology for it to be effective in mitigating the crash.

Age of vehicle fleet

The vehicle age profile was from the 2011 ABS Motor Vehicle Census (ABS, 2011). The census listed the number of registered vehicles by manufacturing year, as of 31 January 2011. As such, the data were adjusted to represent average age in years. The number of vehicles aged zero were those built in 2011 (of which only one month had passed), plus 5/12 multiplied by the number of vehicles built in 2010. The number of vehicles aged one was 7/12 multiplied by the number of vehicles built in 2010, plus 5/12 multiplied by the number of vehicles built in 2009 and so on. This adjustment reflects the concept that in January of a new calendar year no vehicles manufactured in that year have yet been manufactured, whereas by December all of the vehicles will have been manufactured, and on average throughout the year, half of all vehicles made during the year will have completed their run through the vehicle manufacturing plant.

Figure 2 shows the percentage of all vehicles by age. Note that for the grouping aged 21-30 years, this is the average percentage per year of age for vehicles in that age group, and similarly for 31-40 and 41-50. Note that the height of the bar for vehicles aged zero is approximately half the height of those following: if it is assumed that a roughly linear introduction of vehicles into the fleet during their year of manufacture, this is what would be expected.

Percentage of vehicles in the future vehicle fleet

Each year, every vehicle would become one year older. Consequently, if 40% of new vehicles were fitted with AEB technology in a given year, then 40% of all 1-year-old vehicles would have AEB technology in the next year.

The proportion of vehicles at each age was used for all future years. No attempt was made to adjust the attrition rates of vehicle that are fitted with or without the crash avoidance technology, even though these technologies could possibly reduce attrition rate because of a lower number of crashes that occur.

Outcome measures

Outcomes of interest were the penetration of the technology into the total registered vehicle fleet and the predicted percentage of fatalities and injuries that were prevented by the presence of the technologies. The safety benefits that arise because of the AEB technology (“AEB only”) are evaluated separately from the benefits that arise due to both the AEB and V2V technology (“AEB + V2V”) being in the vehicle fleet.

Results

The results are summarized for the effect of AEB only, in Table 3 while the combined effect of AEB and V2V are shown in Table 4. Both tables show:

- the year in which the technologies have a 50% vehicle fleet penetration
- the percent reduction in crashes for the year 2030
- the year in which 25% of crashes are prevented based on the modelling assumptions.

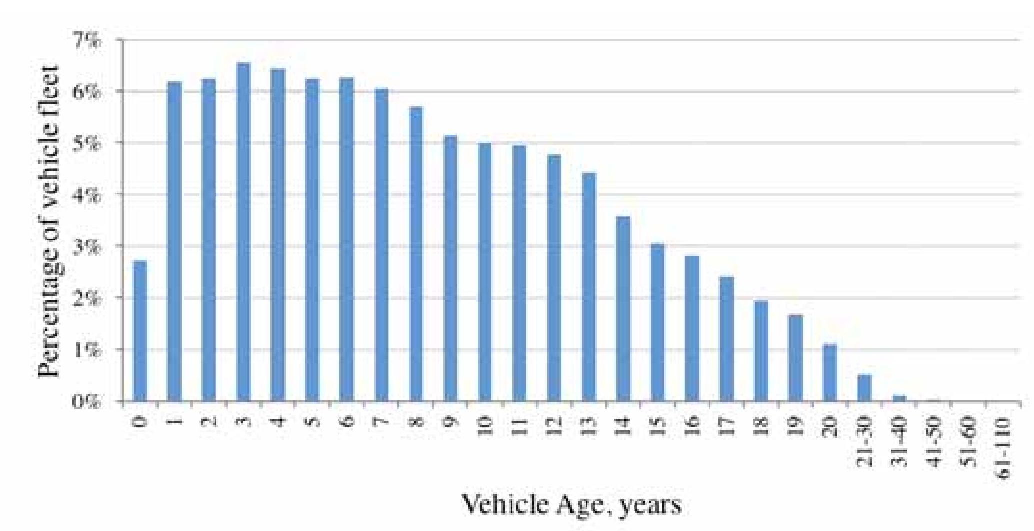

Figure 2. Age distribution of vehicles in the Australian fleet in 2011. Where range of years is given, the percentage is the average percentage per year of age for vehicles in that age group.

Table 3. Fatality and injury reduction results for the three different introduction scenarios for AEB only.

Scenario	Year in which 50% of the vehicle fleet is equipped with AEB	Total reduction in injury crashes in 2030	Total reduction in fatality crashes in 2030	Year in which a >25% reduction in injury crashes is achieved	Year in which a >25% reduction in fatality crashes is achieved
Aggressive introduction	2026	25.0%	20.6%	2030	2036
Encouraged introduction	2028	21.2%	17.5%	2033	2039
Slow introduction	2030	17.1%	14.1%	2036	2042

Table 4. Introduction scenarios for AEB + V2V. Crash reduction includes results from AEB only installations

Scenario	Year in which 50% of the vehicle fleet is equipped with AEB + V2V	Total reduction in injury crashes in 2030	Total reduction in fatality crashes in 2030	Year in which a >25% reduction in injury crashes is achieved	Year in which a >25% reduction in fatality crashes is achieved
Aggressive introduction	2034	26.5%	21.7%	2030	2033
Encouraged introduction	2036	21.9%	18.0%	2032	2035
Slow introduction	2039	17.4%	14.3%	2035	2038

For the AEB only case, an aggressive introduction scenario achieves a 50% fleet penetration of AEB four years earlier than the slow introduction scenario. This earlier 'intervention' results in an additional 7.9% of injury crashes and 6.5% of fatal crashes being prevented in the year 2030 comparing the aggressive AEB introduction scenario to the slow AEB introduction scenario. A 25% reduction of both injury crashes and fatal crashes is achieved 6 years earlier under the aggressive AEB introduction scenario compared to the slow AEB introduction scenario.

Considering AEB + V2V, an aggressive introduction scenario achieves a 50% fleet penetration of the two technologies 5 years earlier than the slow introduction scenario. An aggressive introduction of the combined technologies could potentially result in an additional 9.1% reduction in injury crashes and 7.4% reduction in fatal crashes in the year 2030 comparing the aggressive AEB + V2V introduction scenario to the slow AEB + V2V introduction scenario. A 25% reduction of both injury crashes and fatal crashes is achieved 5 years earlier under the aggressive AEB + V2V introduction scenario compared to the slow AEB + V2V introduction scenario.

These results are plotted for every year between 2010 and 2042 in Figures 3 to 5. The penetration of AEB and V2V technology into the vehicle fleet is shown in Figure 3; the percentage of fatal and injury crashes that are prevented in each year due to AEB only is shown in Figure 4; and the percentage of fatal and injury crashes that are prevented each year due to both AEB and V2V communications is shown in Figure 5.

The figures show that the faster introduction rates prevent a higher number of fatal and injury crashes prevented in each and every year than the slow introduction rates. This means there will be a strong cumulative effect of the crashes being saved every year adding up to ever increasing number of prevented crashes over and above the number prevented by the slower introduction rate.

Conclusions

Autonomous emergency braking technology has been proven to be effective in a range of crash scenarios in the real-world (Fildes et al. 2015; Rosén et al., 2010), despite low prevalence in the vehicle fleet. Its utility has been demonstrated extensively in a theoretical sense and in the early studies of this technology.

Using assumptions about the effectiveness of AEB and V2V based on previous studies, this paper has shown that these technologies, particularly AEB, have the potential to substantially reduce both injury and fatal crashes now and in coming years. The extent to which these technologies can reduce injuries and fatalities is highly dependent on the speed in which they are introduced into new vehicles and consequently into the total registered vehicle fleet. The faster they are introduced in new vehicles, the more crashes will be ultimately prevented.

As noted previously, there are vehicles currently available with various versions of AEB. The vehicle speeds at which these systems operate vary, with some systems focussing on avoidance of low speed rear-end collisions, which may represent the most frequent crash type although may not operate at higher speeds. Other systems are designed for higher travelling speeds, focussing on crash prevention or crash severity mitigation with all road-users. Historically, the focus generally is to market and sell the safety features of AEB to the vehicle purchaser as a means to protect the occupants of that vehicle, like traditional technologies such

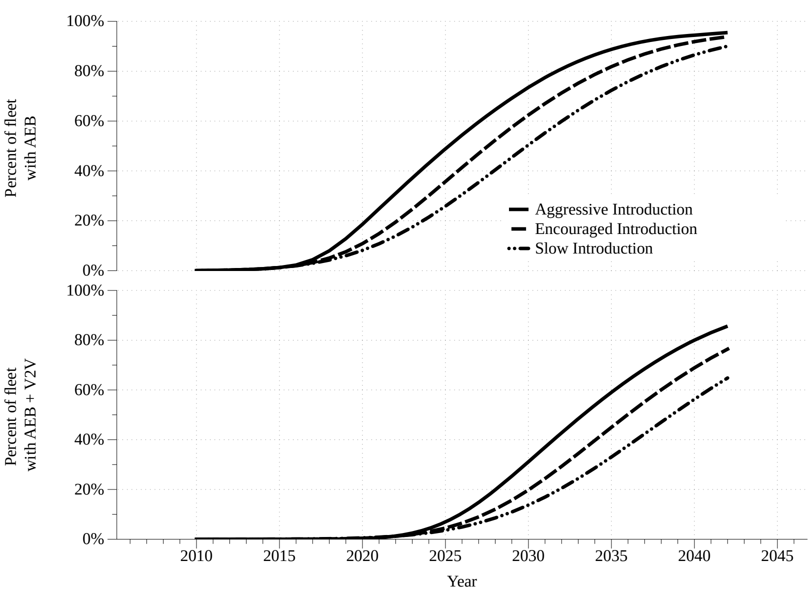

Figure 3. Percentage of vehicles in the whole fleet fitted with AEB (top) or AEB + V2V (bottom) technology

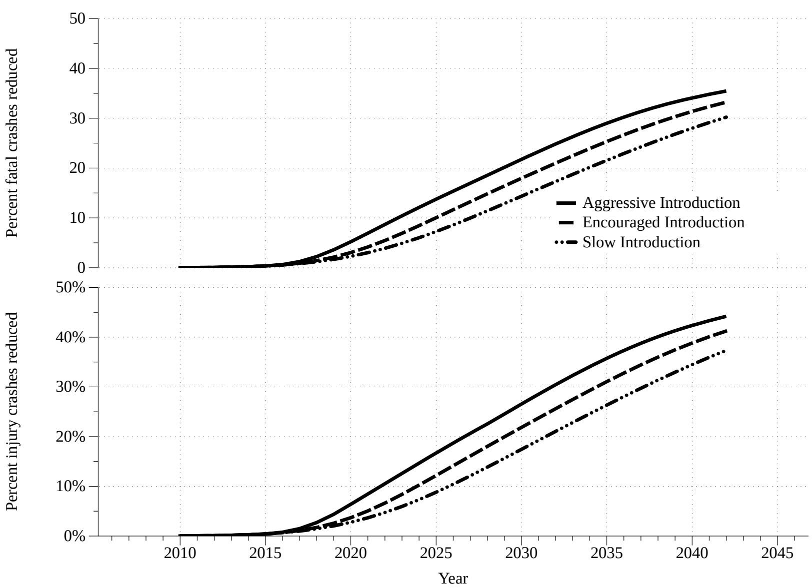

Figure 4. Benefit from the introduction of AEB technology (excluding the effect of V2V) for fatal crashes (top) and injury crashes (bottom)

as airbags. AEB, however, has much potential for the total road safety system, and may be able to avoid collisions and protect vulnerable road users and other vehicle occupants

It is important to note that these technologies will be ineffective if they are not introduced into the vehicle fleet. This paper has demonstrated that the more aggressively the technology is introduced, the more effect it will have at reducing the number of crashes on Australian roads.

Just how many crashes will be affected will depend on the rate that the technology is fitted. In turn this depends on the desire of Australian society to introduce this technology. This desire may be led by individual consumers, consumer organisations or government.

This paper has not discussed the various and numerous push and pull factors that might affect speed of introduction of these technologies. Whilst a governmental design rule could be used to force all new cars to have the technology installed quickly, other less forceful options are possible. These include: making the technology compulsory in 5-star safety rated cars; convincing large fleet buyers to make the technology mandatory on their new car purchases; marketing the technology to consumers through public-health sponsored advertising campaigns; and applying insurance premium discounts to vehicles fitted with the technology. These approaches, or any of many others, when used well, could encourage increased fitment rates.

In this analysis, the reduction in fatalities and injuries were calculated as percentage reduction. The absolute values were not calculated, as it is not known what future changes there will be to the 'baseline' numbers of fatalities and injuries outside of the effects of AEB and V2V. Importantly, however, it was shown that the aggressive introduction scenario is always ahead of the encouraged and slow introduction scenarios in terms of percentage of fatal and injury crashes prevented. This has a cumulative effect that needs to be acknowledged. If an additional 10 or 100 fatal crashes can be prevented every year, on average with a faster introduction rate, then over 20 years this means that there is an additional 200 or 2000 fatal crashes that are prevented. It is difficult to quantify what the total number of crashes this cumulative effect will prevent however, because it is not known what the 'baseline' numbers of crashes will be. The baseline will also be affected by other road safety investments such as to infrastructure, driver training and, potentially, autonomous vehicles.

The calculations in this analysis were based on the current distribution of crash types, and this distribution may change in the future. As technologies for preventing vehicle-to-vehicle crashes become more common, a greater proportion of road trauma may be associated with vulnerable road users. If this is the case, then technologies that prevent crashes with pedestrians, motorcyclists and bicyclists should be encouraged. The calculations in this analysis were also based on single, and possibly conservative, estimates of the effectiveness of AEB and V2V at preventing crashes.

The actual effect will be different depending on the actual effectiveness of these technologies. Despite this, however, the main analysis of this paper, which was the introduction rate of these technologies and its effect on future crash rates does not change with faster introductions leading to greater crash reductions.

This analysis has not considered the different use profiles of newer and older vehicles, including driven kilometres and driver ages. In the analysis, all vehicles were assumed to have a common baseline crash risk. Differences from this assumption could affect the results that were presented.

The technology will have a financial cost, and because this technology is fitted to individual vehicles the cost is most likely to be borne by the consumer. This needs to be balanced against the benefits that the technology is likely to have. For the consumer, there is the benefit of being less likely to be involved in an injury or fatal crash, as well as the benefit of being less likely to repair the vehicle after one of these crashes. For society, there is the benefit of fewer crashes resulting in fewer hospital admissions and economic losses. This paper has not attempted to quantify these costs and benefits, but this should be done before design rules are changed to influence the presence of these technologies.

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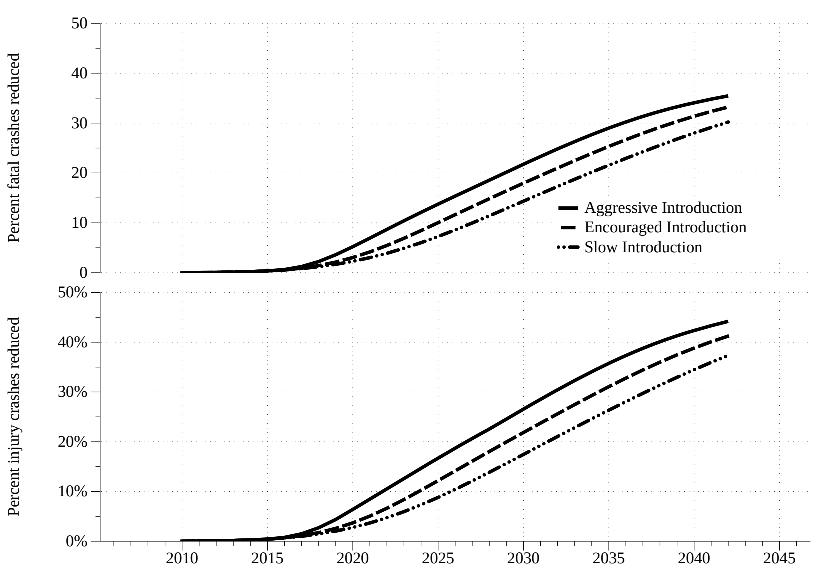

Figure 5. Benefit from the introduction of AEB + V2V technology, including the effect of those vehicles with AEB only for fatal crashes (top) and injury crashes (bottom)

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Understanding driver distraction associated with specific behavioural interactions with in-vehicle and portable technologies

Mitchell L. Cunningham[1], Michael A. Regan[1], Kelly Imberger[2]

[1]*The Australian Road Research Board (ARRB), Sydndey, Australia*

[2]*VicRoads, Melbourne Victoria, kelly.imberge@roads.vic.gov.au*

Corresponding Author: Mitchell Cunningham, 2-14 Mountain St, Ultimo, NSW 2007, Australia. Mitchell.cunningham@arrb.com.au, +61 2 9282 4411.

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Key Findings

- An initial taxonomy was developed that links distraction-related driving behaviours with performance degradation and changes in crash risk for various technologies.
- The link between behaviour, performance and safety outcomes could not be discerned for all technologies and their associated functions.
- The taxonomy developed in this project is, to the knowledge of the authors, the first to use this method to classify specific performance and safety impacts of different technology driver behavioural interactions.
- Development of the taxonomy highlighted gaps in knowledge and suggested avenues for future research to provide performance and safety impacts of distraction related behaviours for in-vehicle technologies.
- The taxonomy is a 'living document' that can be expanded and refined as more research data become available.

Abstract

In-vehicle distraction contributes significantly to road trauma. Consequently, there is a need to understand the level of crash risk and performance degradation associated with driver engagement with in-vehicle technologies. This will assist in better informing the design of legislation and other road safety countermeasures. This study, commissioned by VicRoads, had two aims: (a) to develop a taxonomy that links different technologies (including mobile phones, in-vehicle computer screens, video screens, head-mounted displays and head-up displays), their functions and the specific behavioural actions required of the driver when interacting with them, to changes in driving performance and crash risk; and (b) to identify any gaps in scientific knowledge about crash risks associated with specific driver behavioural interactions with in-vehicle technologies. This involved a literature review and a series of task analyses. The precise links between driver behaviour, performance and safety outcomes could not be discerned for all technologies and their associated functions. However, the taxonomy derived from this study is a 'living resource' that can be expanded and refined as more research data become available.

Keywords

Driver distraction, in-vehicle technologies, taxonomy, human factors, ergonomics

Introduction

Driver distraction has been defined as the "diversion of attention away from activities critical for safe driving toward a competing activity, resulting in insufficient or no attention to activities critical for safe driving" (Regan, Hallett & Gordon, 2011, p. 1776).

In the Australian National Crash In-depth Study (Beanland, Fitzharris, Young, & Lenne, 2013), which utilised this definition in classifying crash data, around 58% of serious injury crashes involved driver inattention as a contributing factor, and 16% involved distraction. In-vehicle distractions, such as driver interaction with passengers and mobile phones, accounted for around 20% of distraction-related crashes. With the evolution of both portable technology applications (e.g. driver interactions with social media on mobile phones) and also the implementation of newer in-vehicle technologies (e.g. head-up displays, touch screens), it is imperative that research is undertaken to assess the implications for driver safety of driver engagement with such technologies. Technologies of interest (as specified by VicRoads) include mobile phones, in-vehicle computer screens, video screens, head-mounted displays and head-up displays.

To this end, VicRoads, the road transport authority in the State of Victoria, Australia, commissioned the ARRB Group to undertake a research study with two aims:

1. Develop a taxonomy that links different technologies, their functions and the specific actions required of the driver when interacting with them, to changes in driving performance and crash risk.
2. Identify any gaps in knowledge about crash risks associated with distracting interactions with in-vehicle technologies that might be explored in the future.

This paper describes the methods used to derive the taxonomy, the findings derived from the research undertaken, and the implications of the study for driver distraction and injury countermeasure development.

Literature Review

A literature review was first conducted to identify known crash risk and/or performance degradation deriving from specific driver interactions with a number of in-vehicle technologies. The technologies of interest in this study were mobile phones (e.g. calls, texts and using social media), navigation, email and music systems, video screens, head mounted displays (e.g. texting with Google Glass) and head-up displays.

Where no information on crash risk was found, the performance degradation of the behavioural interaction alone was identified and documented. If information on crash risk was found, both this data and performance degradation data were documented. Where research indicated different crash risks for different driver groups, these were noted.

A number of reference sources were searched: PubMed, Science Direct, targeted journals (e.g. *Accident Analysis and Prevention*, *Human Factors*, *Traffic Injury Prevention*), conference proceedings and government websites. The abstracts of manuscripts uncovered were read in order to judge whether the study would be appropriate for the present research. Where multiple manuscripts were found investigating similar driver interactions (e.g. impact of mobile phone conversations on driving performance), the more highly-cited paper was selected for review. Meta-analyses and review papers were used, where possible, to reduce redundancy in papers and present aggregate data.

A full systematic literature review was not in the scope of the project and therefore not as many studies were initially uncovered. The only primary inclusion/exclusion criteria for the study was the relevance and appropriateness of the abstracts to the aims of the research.

Taxonomy Development

A distraction by crash risk/performance degradation taxonomy was developed for mobile phones (e.g. calls, texts and using social media), navigation, email and music systems, video screens, head mounted displays (e.g. texting with Google Glass) and head-up displays. This was informed by the outputs of the literature review, and involved the following activities:

1. A Hierarchical Task Analysis (Stanton 1997) was performed by the two lead authors, both with backgrounds in experimental psychology and one a Chief Scientist in Human Factors with expertise in driver inattention and distraction. The analysis involved defining the goal of the interaction with the technology (e.g. "write a text message"), and identifying the generic tasks (i.e., only primary behaviours as identifying all would be impossible) required to accomplish this goal. However these were not documented. For each task, we then derived and documented possible behavioural actions, drawn from the list in Regan, Young, Lee and Gordon (2009), required to support performance of each task (e.g., locating, holding, touching, looking, typing, thinking). If physical interactions with a specific technology were not possible (this occurred for head-mounted and head-up display technologies only) because it was not available, YouTube and other online resources were used to identify potential interactions drivers could undertake in while driving. We then pooled these for all the tasks supporting that goal. Interactions identified from this Task Analysis were also subsequently searched for in the literature to uncover other studies, however no additional studies were uncovered.
2. Using the information above, a series of taxonomy tables was constructed for each technology (Appendix A). Each table was labelled, at the top, according to the technology of interest (e.g., 'Mobile Phone') and contained five rows which contained, from top to bottom, the following information:

- Row 1 – actions associated with driver technology interaction (and function) that have been investigated in the literature (e.g., 'writing text message').
- Row 2 – possible behaviours associated with the actions listed in Row 1 (derived from the task analysis). This row indicates the particular behaviours which have not been specifically investigated in the literature (e.g. the action of dialling a mobile phone, in general, has been investigated, but the literature has not discerned between the behaviours of holding the phone and pressing the buttons to complete the dialling action). All behaviours from the Task Analysis were considered, but only those with evidence to performance degradation and/or links to crash risk are reported.
- Row 3 – types of distraction: visual distraction (visual), auditory distraction (auditory), cognitive distraction (cognitive) and manual interference (manual) that were hypothesised by the authors to occur from driver technology interaction. Thus, the types of distraction that are hypothesised to underlie some or all of the driving performance decrements, and levels of crash risk, are listed in Rows 4 and 5. The distraction types were defined as follows:
    - *visual distraction* was defined as driver distraction triggered by a competing visual activity (e.g., a mobile phone display message)
    - *auditory distraction* was defined as driver distraction triggered by a competing auditory activity (e.g., a mobile phone ringing)

- *cognitive distraction* was defined as driver distraction triggered by internal thought (e.g., thinking about how to compose a text message)
- *manual interference* was defined as observable interference with vehicle control (e.g., steering; accelerator pedal control) by a driver interacting physically with a technology (e.g. lateral deviation of a car brought about by a driver attempting to perform a U-turn with one hand because the other is holding a mobile phone or a driver who steers off the road to the left when reaching left to remove something from the glove box).

- For each of the distraction types arising from the actions in Row 1, an expert judgement was made as to which distraction types for an action were most likely to degrade driving performance (these are bolded in the table).
- Row 4 – driving performance decrements from the literature review, which were associated with driver actions (Row 1).
- Row 5 – driver risks of being involved in a safety-critical event (crash or near-crash) associated driver actions (Row 1). This risk is expressed as an odds ratio - The odds ratio measures the frequency of event occurring relative to the frequency of event non-occurrence. In the domain of crash risk, the odds ratio is defined as the odds of distraction resulting in a crash divided by the odds of a distraction not resulting in a crash event (baseline conditions). If an odds ratio of greater than one is produced then the factor increases risk (e.g. an odds ratio of 2 indicates a double in crash risk), if it is less than one then risk is reduced (e.g. an odds ratio of 0.5 indicates a halving of crash risk). A confidence interval (usually at the 95% confidence level) of how sure a person can be of the results, is calculated for the odds ratio to determine if it is statistically significant (Deeks 2007). The odds ratios were taken directly from the studies/literature reviewed. Bolded odds ratios signify those which were found to be statistically significant.

Information found in Rows 1-3 were derived from the task analysis, while information found in Rows 4 and 5 were derived from the literature review.

Results

The literature review initially identified 65 studies that provided information about (a) driving performance decrements and/or (b) the risk of a safety critical event associated with driver interaction for the technologies of interest. Most were US-based studies.

A final sample of 44 studies was distilled after reading the abstracts to ensure appropriateness and relevance (e.g. investigated the technology of interest). The number of studies per technology group was as follows:

- Mobile phones – 23
- In-vehicle touch/computer screens – 11
- Video screens and radio - 6
- Head-mounted displays – 2
- Head-up displays - 2

More than 60 percent of the 44 papers reviewed appear in reputable peer-reviewed journals (i.e. with impact factors in the higher end of the range for transport journals) or peer-reviewed conference proceedings. Many of the remaining reports were produced by reputable local and international specialist transport safety research centres that require at least internal peer-review of their publications. Most studies found in the literature review reported driving performance decrements. Relatively few studies were found that reported changes in crash risk.

Most studies reviewed did not identify specific behaviours associated with driver engagement for the selected technologies, or their impacts on driving performance and crash risk. The actions that were not specifically examined are identified within each of the tables in Appendix A in the row titled 'Associated actions not specifically investigated' (Row 2). For the specific technologies reviewed, the available literature focused primarily on driver engagement with mobile phones.

Using the research derived from this literature review, a taxonomy was developed that links distraction-related driving behaviours with performance degradation and changes in crash risk for mobile phones (e.g. calls, texts and using social media), navigation, email and music systems, video screens, head mounted displays (e.g. texting with Google Glass) and head-up displays. The task analysis helped identify a number (~15) of possible primary interactions drivers can have with the various technologies. Due to the increased functionality of new devices, such as head-mounted technologies, these were associated with the greatest number of potential driver interactions. Full results are taxonomically-tabulated and presented in Appendix A. Results are discussed below.

Discussion

Using information derived from the relevant tables in Appendix A, the following sections will, where possible, discern how specific technology functions and behavioural interactions have affected driving performance and crash risk (addressing Research Aims 1 and 2, respectively) in *General Observations*. In addition, instances where research has not explored the impact of specific technology functions and behavioural interactions will be highlighted in *Gaps in Knowledge*.

Mobile Phones

Texting - General Observations: Both reading and writing text messages are associated with decrements in driving performance (e.g. Owens et al. 2011) and increased risk of a safety-critical event (Dingus et al. 2016). However, the taxonomy reveals that writing a text message is more detrimental to driving performance than reading a text message (Reed & Robin, 2008). Odds ratios for manual texting ranged from 3.9 to 163.6 (Klauer et al. 2014; Hickman et al. 2010). Findings from the studies reviewed also suggest that texting via voice activation is less detrimental to driving performance than manual texting (e.g. Owens et al. 2011). However, no ORs were available for voice-activated texting. See Table 1.

Texting - Gaps in Knowledge: For both reading and writing text messages, further research is needed to differentiate ORs by driver group, driver experience and other relevant variables. No known ORs have been derived for voice-controlled texting. Analysis of ORs that are associated with internet browsing is also required.

Conversing - General Observations: Table 2 of the taxonomy reveals that the physical act of reaching for and dialling a hand-held mobile phone is associated with decrements in both driving performance (Caird et al. 2008) and an increased risk of a safety-critical event (ORs ranged from 3.3 to 7.1;Farmer et al. 2014; Klauer et al. 2014).

One study suggests driving experience may moderate this relationship and that younger/novice drivers may be at increased risk from reaching for their mobile phone (OR=7.1;Klauer et al. 2014).

Talking on a hand-held mobile phone was not associated with significantly increased crash risk, except for the latest naturalistic driving study which yielded an OR of 2.2 (Dingus et al. 2016). However, research reviewed found this activity produced driving performance decrements, particularly poorer detection of potentially hazardous events on the road.

Conversing on a hands-free phone appears to be associated with similar driving performance decrements to those associated with using a hand-held phone (Caird et al. 2008). However, as indicated above, the Dingus et al. (2016) study shows an increased crash risk of talking on a hand-held phone. One naturalistic driving study (Fitch et al. 2013) found that there was no increase in the risk of a safety-critical event when conversing on a hands-free mobile phone, for both portable hands-free (Bluetooth headset) and integrated (Bluetooth connectivity with in-vehicle speaker) hands-free interactions.

Findings regarding the relationship between conversing on a hands-free mobile phone and crash risk are mixed, with one study suggesting the behaviour is not any riskier than just driving (no mobile phone use; Fitch et al., 2013), and three other studies (Olsen et al., 2009; Hickman et al., 2010; Fitch et al., 2015) suggesting the behaviour may actually be less risky than driving without conversing on a mobile phone. There are number of explanations that may account for these discrepant findings (e.g. see Engström et al. 2005, for impact of cognitive load on driving behaviour).

Conversing - Gaps in knowledge: Table 2 presents findings on the impact of conversing on a mobile phone – for ‘reaching’, ‘dialling’ and ‘talking/listening’. No literature was found that examined the impact on driving performance or safety of ‘receiving’ phone calls or ‘hanging-up’ the phone.

The taxonomy suggests that further research is needed on use of the mobile phone for ‘talking/listening – to (a) understand performance decrements associated with different ways of conversing on a phone ‘hands-free’ and (b) to differentiate ORs by driver group, driver experience and by different ways of communicating hands-free. Different vehicle manufacturers provide alternative solutions for ‘hands-free’ mobile phone use. Some provide voice recognition. Others provide Bluetooth solutions, which eliminate the requirement to touch the phone. However, these can sometimes require complicated driver interactions with controls on the steering wheel and the requirement for the driver to look excessively at phone information displayed on in-car display screens (and increase interference with driving).

Social Media - General Observations: Only one study (Basacik et al. 2011) directly examined the link between use of social media (Facebook) while using a hand-held mobile phone and associated driving performance decrements. Both writing and reading messages through this social network platform were associated with poorer driving performance (Table 3).

Social Media - Gaps in Knowledge: Table 3 outlines the impact of using Facebook on a mobile phone – for ‘writing message’ and ‘reading message’. No literature was found on the impact of ‘receiving message’. No research was found on the impact of social media use on safety in real-life driving studies.

In-vehicle Touch/Computer Screens

Navigation Devices - General Observations: Table 4 suggests that manual destination entry is associated with a greater number of performance decrements compared with input via voice recognition (e.g. Tsimhoni et al. 2004). In addition, the findings reviewed suggest that voice activated systems result in faster destination entry and less deterioration of vehicle control.

Navigation systems that provide only visual directions are associated with greater driving performance decrements than those that provide auditory, or auditory plus visual route-guidance (Dingus et al. 1995). Route-guidance information that is not supplemented with voice-guidance is more visually demanding to process and is likely to interfere with activities critical for safe driving.

Navigation Devices - Gaps in Knowledge: No ORs were identified that are associated with specifically entering a destination or following directions on in-vehicle navigation systems.

Email Systems - General Observations: Findings suggest that opening, checking and replying to emails using in-vehicle email systems that are speech-based are associated with a range of driving performance decrements (Lee et al. 2001; Jamson et al. 2004;Table 4). Thus, although manual interaction is eliminated, there is still distraction. Dingus and colleagues (2016) found an OR of 2.7 for car drivers reading email or checking stocks.

Email System - Gaps in Knowledge: For the three studies reviewed (Lee et al. 2001; Jamson et al. 2004, Dingus et al. 2016), there was no differentiation between the impacts of 'opening', 'checking' and 'replying' to emails in regards to their link with driving performance.

Playing Music - General Observations: Manual interaction with the in-vehicle computer display to browse and select music is associated with greater variability in lateral control according to findings from one study (Kujala, 2013). Another study suggests that voice-activated music retrieval from in-vehicle computers is associated with less eyes off road time than manual interactions with portable MP3 players (Garay-Vega et al. 2010).

Playing Music - Gaps in Knowledge: No known ORs exist in relation to driver behaviours associated with playing music through in-vehicle display systems (not conventional radio;Table 4).

Video Screens, Tablets and Computers

In-vehicle DVD Players - General Observations: The few available studies suggest that watching, listening to and manipulating in-vehicle DVD players can impair activities critical for safe driving (e.g. Hatfield & Chamberlain 2005;Table 5). Watching DVDs and manipulating them appears to degrade performance (specifically vehicle speed, lateral position and driver critical event detection) more than listening to them.

In-vehicle DVD Players - Gaps in Knowledge: No ORs were reported in any of the studies in relation to driver interaction with DVD players (watching, listening, manipulating).

Interacting with Radio - General Observations: Two studies show that the visual-manual task of tuning a radio and simply listening to the radio can impair driving performance (Horberry et al. 2006;Table 5). The latest NDS yields an OR of 1.9 for distraction from in-vehicle radio (Dingus et al. 2016).

Interacting with Radio - Gaps in Knowledge: The taxonomy (Table 5) reveals a lack of research pertaining to the safety risk of interacting with a radio system (tuning and listening).

Head-mounted Displays

Google Glass - General Observations: The taxonomy reveals that text messaging using a head-mounted display (i.e., Google Glass) impairs driving performance compared with not texting at all (Table 6). However, the impairment caused by texting with a head-mounted display appears to be less severe than that associated with visual-manual texting using a smartphone due to the use of voice-activation (He et al., 2015; Sawyer et al., 2014).

Google Glass – Gaps in knowledge: ORs that related to driver interaction with head-mounted displays were not found. In addition, there appears to be no research about the impact on driving performance of using head-mounted displays to access functions other than texting.

Head-up Displays

Head-up Displays - General Observations: The studies reviewed suggest that HUDs in vehicles are less distracting than conventional or head-down displays (e.g. Liu & Wen 2004;Table 7). This is most likely due to the fact that the use of HUD reduces eyes-off-road-time as information is projected directly into the driver's forward line of sight.

Head-up Displays - Gaps in Knowledge: The taxonomy (Table 7) reflects the limited published research on potential distraction resulting from head-up displays (HUDs). The two known studies that have investigated the impact of HUDs on driving performance did not differentiate reported impacts according to the type of behaviours involved, and no ORs were reported. Research is also required on the extent to which information displayed on the HUD itself (e.g. the overlay of vehicle information from the HUD on the external visual scene) may distract drivers from activities critical for safe driving. Other displayed information may include texts, web pages, videos, music lists etc.

General Conclusions

The aim of this project was to attempt to determine, based on a literature review and task analyses, driving behaviours associated with the use of in-vehicle and portable technology, and their associated driving performance and safety outcomes. An initial taxonomy was developed that links distraction-related driving behaviours with performance degradation and changes in crash risk for various technologies. The link between behaviour, performance and safety outcomes could not be discerned for all technologies and their associated functions.

The taxonomy developed in this project is, to the knowledge of the authors, the first to use this method to classify specific performance and safety impacts of different technology driver behavioural interactions.

Development of the taxonomy highlighted gaps in knowledge and suggested avenues for future research to provide performance and safety impacts of distraction related behaviours for in-vehicle technologies. The taxonomy is a 'living document' that can be expanded and refined as more research data become available. This is an important area of study as new technologies continue to come to market and become integrated into vehicles.

There are several practical implications of this research for technology manufacturing (i.e., designing technology to be as ergonomic as possible to avoid distraction), legislation, and public education. Although hand-held mobile phone use, and texting and use of social media for all phones, is banned under the Australian road rules, the research on mobile phone use can be used to inform the public of the risks of specific behavioural interactions when using various phone functions, and for setting penalty levels. The same applies for the use of visual display units (VDUs) and other technologies such as HUDs, which are now available in new vehicles. Public messages may include only using VDUs when the vehicle is stationary, particularly when lists are involved such as during navigation or scrolling for music.

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Appendix A – High-level findings from literature review

Table 1 Performance decrements and safety risk associated with text messaging on mobile phone

Actions investigated	Reading text	Writing: Hand-held (i.e. manual texting)	Writing: Hands-free (i.e. texting using voice only)
Actions not investigated	Locating, holding, looking, thinking	Locating, holding, touching, looking, typing, thinking	Locating, holding, pressing, speaking, looking, thinking, listening (to feedback)
Type of distraction	**Visual**, cognitive, manual interference (hereafter 'manual')	**Visual**, **cognitive**, manual	Visual, **cognitive**, manual
Performance decrements	***Increased reaction time (RT) to hazardous events**** (Reed & Robin 2008) ***Increased lateral variability**** [a] (Reed & Robin 2008) ***Increased longitudinal variability**** (Reed & Robin 2008) ***No effect on driving performance***** (Owens et al. 2011) *Compared with just driving **When message is read to driver by in-vehicle system using text-to-speech software [a]More pronounced in female drivers compared with male drivers	***Increased RT to hazardous events**** (Brookhuis et al. 1991; Törnros & Bolling 2005; Reed & Robin 2008; Drews et al. 2009; Caird et al. 2014) ***Increased lateral variability**** (Cooper et al. 2011; Reed & Robin 2008; Rudin-Brown et al. 2013[a]; Caird et al. 2014) ***More missed traffic signals and driver conflicts*** (Brookhuis et al. 1991; Törnros & Bolling 2005; Cooper et al. 2011; Caird et al. 2014) ***Increased headways**** (Cooper et al. 2011; Caird et al. 2014) ***Longer glances from roadway**** (Owens et al. 2011; Caird et al. 2014) ***Increased lateral and longitudinal variability***** (Reed & Robin 2008) *Compared with just driving **Compared with reading text message [a] Especially prominent in unfamiliar driving contexts (e.g. tunnel)	***Less glances from roadway**** (Owens et al. 2011) ***Increased steering control**** (Owens et al. 2011) ***Increased time spent looking off forward roadway***** (Owens et al. 2011) ***Reduced standard deviation of lateral position****** (He et al. 2013) ***Increased standard deviation of lateral position******* (He et al. 2013) ***Increased RT to hazardous events***** (Yager 2013) ***No difference in RT to hazardous events**** (Yager 2013) *Using integrated vehicle system compared with manual texting, not no texting ** Using integrated vehicle system compared with no texting ***Using speech-to-text software on mobile compared with manual texting, not no texting ****Using speech-to-text software on mobile compared with no texting
Risk	None available	**23.24*** for truck (commercial) drivers (Olson et al. 2009) 1.73***** for car drivers (Fitch et al. 2013) **163.6*** for truck and bus drivers (Hickman et al. 2010) **3.87** for novice drivers (Klauer et al. 2014) **7 (near crash), 5.6 (crash & near crash combined)** for experienced drivers (Victor et al. 2104) **6.1** for hand-held phone (Dingus et al. 2016) *Represents texting in general (reading and writing) and internet browsing via the mobile phone. The studies do not discern the particular risks associated with these different behaviours/functions	None available

Table 2. Performance decrements and safety risk associated with conversing on mobile phone

Actions investigated	Reaching (hand-held mobile)	Dialling (hand-held mobile)	Talking/listening (Handheld)	Talking/listening (Handsfree)
Actions not investigated	Locating, thinking, holding, looking	Holding, pressing, looking, thinking	Holding, thinking	Thinking
Type of distraction	**Visual**, cognitive, **manual**	**Visual**, **cognitive**, **manual**	**Cognitive**, **manual**, auditory	**Cognitive**, auditory
Performance decrements		***Increased reaction time**** (Caird et al. 2008) ***Increased lateral variability**** (Törnros & Bolling 2005) *Compared with just driving	***Increased reaction time to hazards**** (Horrey & Wickens 2006; Caird et al. 2008[a]; Haque & Washington 2013) ***No effect on lateral control**** (Horrey & Wickens 2006; Caird et al. 2008) ***Speed reduction**** (Horrey & Wickens 2006) ***No effect on headway**** (Caird et al. 2008) ***Increased number of missed objects and driving errors**** (Horrey & Wickens 2006) *Compared with just driving [a]This study notes that this decrement is more pronounced in older drivers	***Increased RT to road safety events**** (Strayer et al. 2003[a]; Patten et al. 2004; Caird et al. 2008; Haque & Washington 2013[b]) ***No difference in RT to road safety events***** (Patten et al. 2004; Horrey & Wickens 2006; Caird et al. 2008; Haque & Washington 2013) ***More abrupt and excessive braking**** (Haque & Washington 2015) *Compared with just driving **Compared with talking/listening on a hand-held mobile [a]This study found that this decrement is more pronounced in heavier traffic environments [b]This study found the decrement to be more pronounced in provisional-licence drivers compared with open-licence drivers
Risk	**7.05** for novice car drivers, 1.37 for experienced car drivers (Klauer et al. 2014) **3.31** for experienced car drivers (locating/reaching) (Farmer et al. 2014) **3.38** for truck and bus drivers (Hickman et al. 2010) **3.65** for car drivers (Fitch et al. 2013) 1.7 for car drivers (Victor et al. 2014)	**2.8** for experienced car drivers (Klauer et al. 2006) **5.93** for truck (commercial) drivers (Olson et al. 2009) **3.5** (Hickman et al. 2010) **8.32** for novice car drivers, **2.49** for experienced car drivers (Klauer et al. 2014) **2.77** for car drivers (Farmer et al. 2014) 0.63 (pressing to begin/end all only) for car drivers (Fitch et al. 2013) **12.2** for car drivers (Dingus et al. 2016)	1.3 for experienced car drivers (Klauer et al. 2006) 1.0 for truck (commercial) drivers (Olson et al. 2009) 0.79 for truck and bus drivers (Hickman et al. 2010) 0.79 for car drivers (Fitch et al. 2013) 4.1 for car drivers (McEvoy et al. 2005) 0.61 for novice car drivers and 0.76 for experienced car drivers (included hands-free) (Klauer et al. 2014) 0.90 for experienced drivers (talking/listening/using voice commands) (Farmer et al. 2014) **1.2** for commercial drivers when not at a junction (Fitch et al. 2015) 1.1 for light vehicle drivers when not at a junction (Fitch et al. 2015) **2.2** for car drivers (Dingus et al. 2016)	2.37 for experienced car drivers (Farmer et al. 2014) **0.44** for portable hands-free for truck (commercial) drivers (Olson et al. 2009) **0.65** for truck and bus drivers (Hickman et al. 2010) 0.73 for portable hands-free for car drivers (Fitch et al. 2013) 0.71 for integrated hands-free for car drivers (Fitch et al. 2013) **0.44** for portable hands-free for commercial drivers when not at a junction (Fitch et al., 2015)

Table 3. Performance decrements and safety risk associated with using social media on mobile phone

Actions investigated	Manually writing message (handheld)	Reading message (Handheld)
Actions not investigated	Locating, holding, touching, looking, scrolling, typing, thinking	Locating, looking, holding, pressing, touching, scrolling, thinking
Type of distraction	**Visual, cognitive, manual**	**Visual, cognitive**, manual
Performance decrements	*Slower mean speed** *Greater standard deviation of speed** *Increased lateral variability** *Increased variability in headway** *Longer glances off forward roadway** *30% increase in reaction time** Basacik et al. (2011) *Compared with just driving	*Slower mean speed** *Increased variability in headway** *Longer glances off forward roadway** Basacik et al. (2011) *Compared with just driving
Risk	None available	None available

Table 4. Performance decrements and safety risk associated with in-vehicle navigation, in-vehicle email and music systems

Actions investigated	Navigation - Entering destination (manual)	Navigation - Entering destination (voice)	Navigation - Following directions (w/ voice guidance)	Navigation - Following directions (visual only)	Email - Opening, checking, replying (speech-based)	Play music - Browsing/select music
Actions not investigated	Looking, touching, pressing, typing, scrolling, thinking	Pressing (turn on voice-control), looking, thinking, speaking, listening	Listening, thinking, looking	Looking, thinking	Looking, speaking, listening, thinking	Looking, touching, pressing, scrolling, thinking
Type of distraction	**Visual**, **cognitive**, **manual**	**Visual**, **cognitive**	**Visual**, **cognitive**, auditory	**Visual**, **cognitive**	**Visual**, **cognitive**, auditory	**Visual, cognitive, manual**
Performance decrements	***Increased lateral deviation**** (Tsimhoni et al. 2004; Tsimhoni & Green 2001) ***Increased number of braking errors**** (Dingus et al. 1995; Tsimhoni & Green 2001) ***Increased number of glances off roadway****	***Reduced lateral variability**** (Gärtner et al. 2001; Tsimhoni & Green 2001; Tijerina et al. 1998; Tsimhoni et al. 2004) ***Less frequent glances off forward roadway**** (Gärtner et	***Reduced lateral deviations**** (Dingus et al. 1995) ***Less braking errors**** (Dingus et al. 1995) ***Less number of glances away from roadway**** (Dingus et al. 1995) *Compare-d with	***Similar glance activity away from road and lateral variability**** (Dingus et al. 1995) *Compared with using a conventional map	***Increased RT to hazardous events**** (Lee et al. 2001) ***Fewer corrective steering movements **** (Jamson et al. 2004) ***Longer headways**** (Jamson et al. 2004)	***Greater variability in lateral control***[a] (Kujala 2013) ***Greater number of glances off forward roadway***** (Garay-Vega et al. 2010). *Compared with just driving **Compared with voice-activated system [a]This decrement more pronounced

Actions investigated	Navigation - Entering destination (manual)	Navigation - Entering destination (voice)	Navigation - Following directions (w/ voice guidance)	Navigation - Following directions (visual only)	Email - Opening, checking, replying (speech-based)	Play music - Browsing/select music
	(Chiang et al. 2001) ***Reductions in speed**** (Chiang et al. 2001) *Compared with just driving	al. 2001; Tsimhoni & Green 2001; Tijerina et al. 1998) *Compared with manual input	methods without voice-guidance		***Increased braking time**** (Jamson et al. 2004) *Compared with just driving	for swiping methods instead of point-touching
Risk	None available	None available	**4.6** for car drivers (Dingus et al. 2016) – not this is for "interacting with a non-radio/no-heating, ventilation and air conditioning (HVAC) in-vehicle device (e.g. touch screen menus) – thus presumed to include navigation		**2.7** for car drivers reading email or checking stocks (Dingus et al. 2016)	None available

Table 5. Performance decrements and safety risk associated with in-vehicle video screens and radio

Actions investigated	DVD - Watching	DVD -Listening only	DVD - Manually manipulating	Radio - Manual tuning	Radio - Listening only
Actions not investigated	Looking, thinking, listening	Thinking	Looking, touching, pressing, thinking, holding, inserting	Looking, touching, thinking	Thinking
Type of distraction	**Visual**, **cognitive**, auditory	**Cognitive**, auditory	**Visual**, **cognitive**, **manual**	**Visual,** cognitive, **manual**	**Cognitive,** auditory
Performance decrements	***Increased speed variability**** (Hatfield & Chamberlain 2005) ***Increased RT to hazardous events**** (Kircher et al. 2004; White et al. 2006) ***Increased braking times**** (Hatfield & Chamberlain 2005) ***Longer glances off forward roadway**** (Funkhouser & Chrysler 2007[a]) ***Increased lateral variability on curves**** (Hatfield & Chamberlain 2005) *Compared with just driving [a]This study used a	***No effect on lateral variability**** (Hatfield and Chamberlain 2005) ***No effect on speed variance**** (Hatfield & Chamberlain 2005) ***Increased braking times**** (Hatfield & Chamberlain 2005) ***No effect on RT to hazardous events**** (White et al. 2006) *Compared with just driving	***Greater average scaled lateral accelerations**** (Funkhouser & Chrysler 2007) [a] ***Slower mean speed**** (Funkhouser & Chrysler 2007) [a] ***Increased RT for hazardous events**** (Funkhouser & Chrysler 2007) [a] ***Less accurate peripheral detections**** (Funkhouser & Chrysler 2007) [a] ***Increase in braking time**** (Funkhouser & Chrysler 2007) [a] *Compared with just driving	***Degraded speed control*** (Horberry et al. 2006) ***Delayed responses to unexpected hazards*** (Horberry et al. 2006) *Compared with just driving	***Degrade lane keeping performance**** (Jäncke et al. 1994) *Compared with just driving

Actions investigated	DVD - Watching	DVD -Listening only	DVD - Manually manipulating	Radio - Manual tuning	Radio - Listening only
	portable DVD player strapped to passenger seat (facing driver)		[a]This study used a portable DVD player strapped to passenger seat (facing driver)		
Risk	None available	None available	None available	**1.9** for in-vehicle radio [task not specified] (Dingus et al. 2016)	**1.9** for in-vehicle radio [task not specified] (Dingus et al. 2016)

Table 6. Performance decrements and safety risk associated with using head-mounted displays

Actions investigated	Writing text message (using voice input into Google Glass)
Actions not investigated	Listening (for incoming message), tilting head, looking, reading, speaking, thinking, swiping (frame to turn off display)
Type of distraction	**Visual**, **cognitive**, **manual** (head tilting)
Performance decrements	***Reduced standard deviation of lateral position**** (He et al. 2015) ***Reduced number of lane excursions**** (He et al. 2015) ***Greater standard deviation of steering wheel position***** (He et al. 2015) ***Reduced standard deviation of steering wheel position****** (He et al. 2015) ***Greater braking response time**** (He et al. 2015) ***No difference in braking response time****** (He et al. 2015) ***Lower headway distances****** (He et al. 2015) ***No difference in headway distances***** (He et al. 2015) ***Better lane keeping performance***[a] (Sawyer et al. 2014) ***Adopted closer headways***[a] (Sawyer et al. 2014) *Compared with texting using Smartphone (both manually and using voice activation). No difference in this decrement when compared with just driving **Compared with just driving ***Compared with texting using Smartphone (both manually and using voice activation) [a]Compared with manual texting
Risk	None available

Table 7. Performance decrements and safety risk associated with using head-up displays

Actions investigated	Navigation and speed maintenance
Actions not investigated	Depends on functions implemented on head-up display Predominantly looking, thinking
Type of distraction	Visual cognitive
Actions investigated	Navigation and speed maintenance
Performance decrements	***Increased speed control****** (Liu & Wen 2004) ***Increased steering control****** (Liu 2003; Liu & Wen 2004) ***Reduced RT for hazardous events****** (Liu 2003; Liu & Wen 2004) *Compared with conventional or head-down display
Risk	None available

Road Safety Policy & Practice

Vulnerable road users in a Safe System

Trevor Bailey[1] and Jeremy Woolley[2]

1 Centre for Automotive Safety Research (CASR), University of Adelaide, South Australia, trevor@casr.adelaide.edu,au

2 CASR (as above), jeremy@casr.adelaide.edu.au

Corresponding Author: Trevor Bailey, Centre for Automotive Safety Research, University of Adelaide, South Australia 5005, trevor@casr.adelaide.edu.au, +61 8 8313 0916.

Key Findings

- Vulnerable road users tend to be poorly accounted for in Safe System models.
- Safe Systems involve more than just susceptibility to crash forces and forgiving systems.
- Studies of traffic conflicts of vulnerable road users can extend Safe System thinking.

Abstract

Road users such as pedestrians, cyclists and motorcyclists are highly susceptible to crash forces. Yet, while Safe System thinking accords susceptibility to crash forces and a forgiving system as focal principles, the greater vulnerability of these road users is barely recognised in many models of a Safe System. This is a concern of growing importance, given current efforts to increase usage of active travel modes and substantially rising injury rates among cyclists and motorcyclists. This paper explores a selection of research studies aiming to identify relevant factors behind traffic conflicts involving vulnerable road users, as a means to determine appropriate countermeasures particularly those involving infrastructure and vehicle technology. A better understanding of the contextual nature and causes of traffic conflict has much potential to contribute to Safe System thinking and conceptualisations, allowing them to extend beyond their traditional focus on susceptibility to crash forces and systems that are forgiving.

Keywords

Active travel, Cyclists, Pedestrians, Safe System, Vulnerable road users

Introduction

Vulnerable road users, namely pedestrians, cyclists and motorcyclists, constitute the road user groups most susceptible to death and injury from crash forces. The ability of the human body to withstand crash forces, or human physical frailty, is a focal principle in many conceptualisations of Safe System thinking found in documents such as the *National Road Safety Strategy 2011-2020* (NRSS) (Australian Transport Council (ATC), 2011). The NRSS emphasises two other principles inherent in Safe System thinking: that humans make mistakes, and the need for a 'forgiving' transport system.

The NRSS champions its Safe System approach as a holistic one, inclusively catering for all road user groups, without favouring one over another. However, this paper considers that the heightened risk borne by vulnerable road users due to their greater frailty relative to other road users deserves more consideration in many road safety strategies' conceptualisations and accounts of Safe System approaches. In particular, there is a need for improved understanding of what should constitute a Safe System approach that is more accountable to vulnerable road users. This need is of growing importance, given that the Australian Government has committed to increasing levels of active travel, such as walking and cycling (Department of Infrastructure & Transport (DIT), 2013), and that motorcycle riding is currently increasing in frequency (Australian Bureau of Statistics (ABS), 2014).

This paper evolved out of work undertaken for Austroads (Lydon, Woolley, Small et al., 2015), involving reviewing the implementation status of the NRSS (as the NRSS required such a review to be undertaken in 2014). The review was aimed at identifying for road safety decision makers a limited number of new or enhanced road safety initiatives or potential areas for more focussed implementation. During this work, it became apparent to its authors that some concern was being expressed in recent research literature that there should be a more concerted focus on the circumstances and needs of vulnerable road users within Safe System thinking and planning. In particular, while Safe System conceptualisations and approaches rightly stress the need for such a system to be forgiving of human error and crash forces, this needs to be balanced with approaches that aim to minimise, if not eliminate, the potential for conflicts to occur within traffic streams, as traffic conflicts are often especially hazardous to vulnerable road users. Indeed, the Austroads review recommended, as a potential follow-up action, that further research be undertaken to clarify this very point.

This paper is best considered as a discussion emanating from that previous work. Several aspects of Safe System thinking pertinent to vulnerable road users are not discussed, however, (including safe speeds, road law complance by vulnerable road users, and pedestrian impact protection on vehicles), as these areas were not required focusses for the original work undertaken.

Methods

A selective review of research literature was conducted, chosen for its potential to support a renewed consideration of the place of vulnerable road users within Safe System thinking and planning. Relevant literature was searched using the following databases: *Transport Research International Documentation (TRID),* Informit Online, ScienceDirect and the CASR library database by using the search terms: vulnerable road user, pedestrian, cyclist, motorcyclist, walking, infrastructure, vehicle technology, vehicle safety, Safe System. The literature search was confined to references from 2012 as the work required for Austroads purposely focussed on identifying new or recent information. The original search identified 172 research-related items relevant to vulnerable road users. When it became apparent during the NRSS review that there is an emergent view suggesting a need to reconsider the status of vulnerable road users in Safe System thinking, 29 of the items were subsequently chosen for their potential contribution to illustrating the emergent view in more detail.

Increasing travel among vulnerable road users

There is growing recognition, including from the Australian Government (DIT, 2013) that, not only are more Australians undertaking walking and cycling trips more often, but policies of active travel (including workplace health and safety policies) are urging them to do so. Travel survey data show that not only do most Australians walk at some stage during their day, but that almost 4% of journeys to work or full-time study involve walking. In some inner city locations, and in major activity centres, the mode share of walking across all purposes *is much higher than for any other mode of transport* (DIT, 2013, p. 5, emphasis added). Moreover, four out of ten people (43.7%) regularly walk for reasons other than accessing work or study, typically shopping (ABS, 2012). Every day, around 178,500 people cycle to work (representing 1.6% of mode share). As well, around 517,600 ride a bike for other purposes, representing 4.8% of mode share (ABS, 2012).

An indication of increased frequency in motorcycle riding can be gleaned from the motor vehicle registration data collated by the ABS (2014). In 2014, motorcycles comprised 4.4% of all vehicle registrations nationally. However, motorcycle registrations between 2009 and 2014 increased by 25%, which was the highest growth rate over that period out of all types of vehicle, with increases in registrations of light rigid trucks and campervans following in second and third place. The average annual growth rate for motorcycle registrations over 2009-2014 was 4.7%. (ABS, 2014)

The European Transport Safety Council (ETSC) (Adminaite, Allsop & Jost, 2015) has noted the safety implications of increasing engagement in active travel, particularly cycling and walking, but that these safety implications are not necessarily negative ones. Some countries (such as the Netherlands and Sweden) have high cyclist and pedestrian participation rates but with relatively low crash involvement (Adminaite, Allsop & Jost, 2015). Moreover, because of their lower speed and mass, cyclists and pedestrians do not endanger other road users as much as vehicle drivers do. Therefore, the ETSC argues, car drivers who also engage in walking or cycling can, if accompanied by measures to reduce the risks of walking and cycling, increase overall road safety. (Adminaite, Allsop & Jost, 2015)

Vulnerable road users among road fatalities and injuries

Over the past five years in Australia, up to one in five road deaths involved a pedestrian or cyclist. About one in six involved a motorcycle rider or passenger. Table 1 shows the proportions of fatalities that involved pedestrians, cyclists and motorcyclists (out of all road fatalities), for each 12 month period ending in April, and across 2011-2015, based on data published by the Bureau of Infrastructure, Transport and Regional Economics (BITRE, 2015).

Table 1. Pedestrian, cyclist and motorcyclist fatalities, Australia, 2011-2015

12 months ended April	Pedestrian		Cyclist[a]		Motorcyclist[a]	
	n	**%**	**n**	**%**	**n**	**%**
2011	174	13.1	28	2.1	223	16.8
2012	189	14.9	33	2.6	200	15.8
2013	153	11.9	36	2.8	217	16.9
2014	164	14.0	58	5.0	193	16.5
2015	162	13.8	34	2.9	206	17.5

[a]includes passengers (for both cyclists and motorcyclists)

It can be seen in Table 1 that pedestrians accounted for between 11.9% and 14.9% of all road fatalities in Australia during April 2011 to April 2015. Cyclists accounted for 2.1% to 5.0% and motorcyclists 15.8% to 17.5% over the same period. BITRE (2015) also reported that, on average over 2011-2015, pedestrian fatalities declined by 2.8% and motorcyclist fatalities by 3.2%, while cyclist fatalities increased by 10%. Nonetheless, Australian motorcyclists per distance travelled have experienced a fatality rate approximately 30 times that of car occupants, and a serious injury rate 41 times that of car occupants (Johnson, Brooks & Savage, 2008).

Using case data supplied by the National Hospital Monitoring Database (NHMD), which is operated by the Australian Institute of Health and Welfare (AIHW), the Austroads review of the NRSS (Lydon et al., 2015) examined recent rates of serious injuries among cyclists and pedestrians. It found that, while rates of pedestrian serious injuries were gradually declining, rates of injury among cyclists and motorcyclists have been rising dramatically since at least 2001. In 2001, motorcyclists and cyclists accounted for 29% of serious injury cases, rising to 38% in 2010. Moreover, the absolute increase in hospitalised cases involving motorcyclists and cyclists was many times larger than the absolute decline in fatal cases. In fact, the review considered the substantial rise in cyclist and motorcyclist serious injury accounted for the overall rise in serious injury when totalled across *all* road user groups (Lydon et al., 2015).

Further analysis in the Austroads review considered that the upward injury trend among cyclist and motorcyclist cases was "especially steep" for men aged 45 to 64. Also, as might be expected, the rise was much more marked for cases that occurred in on-road traffic than for non-traffic cases, and for cyclists was most marked among residents of major cities than elsewhere (Lydon et al., 2015).

In sum, up to one in five Australian road fatalities involves a pedestrian or cyclist, and up to one in six involves a motorcyclist. Cyclist fatalities and serious injuries, along with motorcyclist injuries, are rising substantially. Such increases dramatically illustrate the greater susceptibility of vulnerable road users to crash forces which, together with the growing participation in walking, cycling and motorcycling, provides a strong impetus for road safety strategies' conceptualisations and accounts of their Safe System approaches to accord greater respect towards vulnerable road users than they currently tend to do.

Safe System thinking

In 2008, the OECD and the International Transport Forum (ITF) reported that several countries had adopted a Safe System approach for their road safety policies and programs, including Sweden's *Vision Zero* and the Netherlands' *Sustainable Safety*. The OECD/ITF added that, while different jurisdictions share similar core principles of Safe System thinking, more specific details of the approaches are suggested by differences between countries. Similarly, Johnston, Muir and Howard (2014) more recently noted that, despite the mutability of Safe System conceptualisations, fundamental aims and principles endure. A central aim common in Safe System approaches is to better manage the forces involved in a crash such that, when an error leads to a crash, no individual road user is exposed to levels of force that exceed the capacity of the human body to withstand those forces (OECD/ITF, 2008; Johnston, Muir & Howard, 2014). Traffic safety agencies need a deep understanding of such critical factors in the road and traffic environment, along with safer road users, safer vehicles and infrastructure, and safe travel speeds, as these factors influence the most prevalent types of crash (OECD/ITF, 2008; Johnston, Muir & Howard, 2014). These aims and understanding are all the more vital when those involved in crashes are road users who by definition are the most vulnerable due to their limited capacity to withstand crash forces.

Vulnerable road users in current Safe System thinking

The NRSS (ATC, 2011) acknowledges pedestrians as having one of the highest rates of death and injury among vulnerable road users as a group, yet pedestrians in relation to a Safe System receive no dedicated coverage in that strategy apart from a short mention that they benefit from lower vehicle speeds and certain infrastructure treatments such as school speed zones and pedestrian crossings.

Similarly, the NRSS provides little more than passing references to cyclists as vulnerable road users. While the document sees the Safe System approach as underpinning the entire strategy, it is essentially applied to motorists rather than vulnerable road users (Shaw, Poulos, Rissel et al., 2012). Moreover, while major cycling documents such as *The Australian National Cycling Strategy 2011-2016* (Austroads, 2010) and Austroads guides relevant to cycling (van den Dool, Murphy & Botross, 2014; Jurewicz, Steinmetz & Phillips et al., 2014) both state that the Safe

Table 2. Summary of reviewed traffic conflict studies

Context of traffic conflict study	Findings relevant to Safe System	Reference
Pedestrian crashes at signalised pedestrian crossings	Shortened pedestrian crossing times increased pedestrian – vehicle conflicts	Greater London Authority (2014) (UK)
Longitudinal data of pedestrian – vehicle crashes	Identification of priority locations for intervention treatments	Kronenburg, Woodward & DuBose et al. (2015) (USA)
Vehicle distance as proxy for random driver error	Weak association of driver error with pedestrian – vehicle crashes, but such crashes had strong association with system errors	Dumbaugh and Li (2011) (USA)
System failures and extreme behaviours as causes of fatal crashes	Majority of crashes ensue from failings of the road system	Wundersitz, Baldock & Raftery (2014) (Australia)
Holistic pedestrian safety evaluation methods	Methods of identifying traffic situations and locations relevant to pedestrian – vehicle conflicts	Tolford, Renne & Fields (2014) (USA)
Drivers, cyclists and motorcyclists' situational awareness along the same traffic route	Drivers, cyclists and motorcyclists exhibited different situational awareness of the same road features, giving potential for traffic conflicts	Salmon, Lenné & Walker, et al. (2013) (Australia)
Cyclist collisions at intersections where cyclist has right of way	Traffic conflict reduced with installation of cycle crossings and deflecting cyclist pathways on intersection approaches	Schepers (2013) (Netherlands)
Cyclist collisions at roundabouts	Increased crashes found at roundabouts explained by increased numbers of cyclist – vehicle conflict situations	Harris, Reynolds & Winters et al. (2013) (Canada)
Cyclist collisions in local area streets	Local streets with painted cycle lanes were safer if infrastructure diverted motorised traffic away from the streets with cycle lanes	Harris, Reynolds & Winters et al. (2013) (Canada)
Cycle track infrastructure	Attractive infrastructure on designated cycle tracks increases patronage, thereby reducing cyclist-vehicle conflicts on busy roads	Nuworsoo, Cooper & Cushing et al. (2012) (USA)
Traffic conflicts involving motorcyclists	Infrastructure treatments identified through discussion of motorcyclist traffic conflicts with highway design specialists and motorcycling groups	Schaffer, Heuer & Bents et al. (2011) (USA) Nicol, Heuer &Chrysler et al. (2012) (Europe)
Vehicle drivers' responses to pedestrian and cyclist behaviours	(study is ongoing)	Chrysler & Hamann (2015) (USA)
Effects of various vehicle technologies on vulnerable road users	Technologies that enhance the detectability and visibility of vulnerable road users have high potential to increase the safety of those users	Scholliers, Bell & Morris et al. (2014) (Europe)

System approach is relevant to cyclist (and pedestrian) infrastructure, these documents tend to focus on the needs of individual cyclists yet offer few detailed suggestions as to how to apply Safe System principles to promote cycling safety in the *broader* context of the transport system.

Compared to its coverage of pedestrian and cyclist safety, the NRSS (ATC, 2011) provides much more detail for motorcyclist safety. This may be because, as the NRSS states, motorcyclist deaths have increased by 17% over the past decade, reflecting in part the increased usage of motorcycles over this time. However, while the NRSS says it recommends infrastructure treatments in response to these trends, it provides little further detail.

Some recent road safety action plans of individual Australian jurisdictions reflect a growing understanding of a need for increased emphasis on vulnerable road users in light of active travel trends. For example, the New South Wales action plans for cyclists and pedestrians (Transport for New South Wales, 2014a, 2014b) developed in consultation with user groups, call for cycling corridors rather than isolated facilities, consideration of the needs of cyclists on high speed roads, consistency across pedestrian areas in reduced speed limits, more pedestrian-friendly crossings and encouraging new vehicle technologies that are sensitive to the needs of vulnerable road users.

Some European countries, such as Sweden (Tingvall, Ifver & Krafft et al., 2013), are also recognising a need to accord greater emphasis to vulnerable road users in road safety strategies. Recently, the ETSC noted that some countries had established an urban street user hierarchy, giving the highest usage priority to walking, cycling and public transport modes, based on a "principle of prudence" (Adminaite, Allsop & Jost, 2015, p.19) governing the relationship between drivers and vulnerable road users and new approaches to urban road planning.

Enhancing the status of vulnerable road users in Safe System thinking

Given the growth in walking, cycling and motorcycling and the increased frequency of serious injury among cyclists and motorcyclists, the need for safe relevant infrastructure is paramount. Beyond the NRSS, the Australian Government's Department of Infrastructure and Transport (DIT) acknowledges that a key barrier to efforts to increase walking and cycling is inappropriate infrastructure in relation to the speed and volume of traffic (DIT, 2013). It calls for:

- separation of pedestrians and cyclists from fast traffic
- ensuring walkways and cycle paths are constructed appropriately for their tasks (including disability access); and
- prioritising pedestrian and cyclist travel in high-pedestrian areas at the same time as reducing traffic volume and speed through these areas.

Implicit in these actions is the need to ensure that the infrastructure called for is 'forgiving' of crash forces as a consequence of human error or fallibility. But should such traditional emphasis on a forgiving system be sufficient in Safe System thinking when vulnerable road users are considered? World-renowned road safety expert Professor Fred Wegman has cautioned, "While the Safe System concept has been present in Australia for many years, its implementation still proves a challenge…" (Wegnman, 2012, p. 5). In relation to vulnerable road users, this challenge may only partly lie in a Safe System's traditional call to develop and implement forgiving initiatives that reduce the effects of crash forces when humans make mistakes. Some recent vulnerable road user research is revealing potential value in implementing Safe System approaches that emphasise not just forgiving infrastructure, but endeavouring to minimise, if not eliminate, traffic conflicts and particularly conflicts between vehicles and vulnerable road users.

A broad range of such traffic conflict studies considered in the Austroads review of the NRSS are summarised below in Table 2. Taken collectively, they constitute a strong foundation for reconsidering the status accorded to vulnerable road users in Safe System thinking.

The first study listed in Table 2 illustrates that simply installing more pedestrian safety infrastructure will not necessarily reduce pedestrian road trauma if there are problems with the way that infrastructure operates, and particularly if pedestrian-vehicle conflicts are not reduced as a result. The Greater London Authority (GLA, 2014) realised this when it investigated why a quarter of its pedestrian crashes occurred at pedestrian crossings. The GLA found that 'green man' crossing times had been reduced in the interests of achieving a smooth flow of vehicular traffic. However, this was having the effect of encouraging some pedestrians to take greater risks to 'beat' the green light change, and discouraging some older and disabled pedestrians from using particular crossings altogether, and perhaps then attempting to cross at locations without pedestrian crossings. To solve the apparent dilemma, the GLA recommended increasing the installation of cameras that can detect the numbers of pedestrians at a crossing and their speed of crossing, and adjust each signal phase accordingly.

The GLA study provides a microcosmic illustration of the importance of studying potential traffic conflicts in their broader (Safe System) contexts. The City of San Francisco (Kronenberg, Woodward & DuBose et al., 2015) examined longitudinal data of its pedestrian-vehicle crashes to classify the most frequent crash types at sites experiencing the most pedestrian crashes. Teasing out various factors in the road system, as well as relevant human and environmental factors, afforded a data-driven planning process for interventions at priority locations to reduce pedestrian-vehicle conflicts.

Major system-level work in North America by Dumbaugh and Li (2011) suggests that crashes, including those involving pedestrians and cyclists, are the product of systematic patterns of behaviour *associated with the built environment* rather than merely the result of errors by drivers. Using vehicle miles of travel as a proxy for random error by drivers, their regression analyses found a weak association of driver error with crashes involving motorists and pedestrians. However, stronger associations were found between such crashes and system error characteristics of the built environment. Dumbaugh and Li considered that the factors associated with a vehicle crashing into a pedestrian (or into a cyclist) are largely the same as those resulting in a crash with another vehicle. These two researchers rightly pointed out that the correlations they found are not proof of causation and research is needed into how drivers and other road users adapt their behaviours in response to the built environment and how those behaviours may affect their exposure to crash risk. Nonetheless, substantial analytical work in Australia by Wundersitz, Baldock and Raftery (2014) has, similarly to Dumbaugh and Li, concluded that relatively few road crashes are the consequence of extreme behaviour, rather, the vast bulk should be interpreted as failings of the broader road system.

Dumbaugh and Li (2011) believe their results suggested that improvements to urban traffic safety require designers to balance the 'inherent tension between safety and traffic conflicts, rather than simply designing roadways to be forgiving' of human error (2011, p. 69). The NRSS (ATC, 2011), under 'Safer Roads', does not use the word 'forgiving' in relation to infrastructure, merely saying that road and roadside treatments are important for preventing crashes or minimising crash consequences. Nonetheless, this coverage is still one step removed from Dumbaugh and Li's assertion that the real focus should be on addressing the tension between safety and traffic conflicts brought about by the built environment.

One prime example of such tension is that the spatial distribution of pedestrian crashes shows that they cluster around urban arterial roads, which are typically designed for higher vehicle speeds (Dumbaugh & Li, 2011). This often results in pedestrian (and cyclist) advocates calling for design features that reduce driver speeds and which buffer pedestrians (and cyclists) from oncoming traffic. However, while these approaches serve to reduce the opportunities for conflicts between motorists, pedestrians and cyclists, they do not focus on addressing the *causes* of those conflicts that Dumbaugh and Li contend stem from system error in the built environment rather than from human error.

This need to understand system errors as causes of traffic conflicts appears to be reflected in what has become known as the 'Complete Streets' movement in the USA (Schlossberg, Rowell & Amos et al., 2015). The concept of Complete Streets challenges the traditional priority accorded to vehicular mobility and flow along major streets in favour of focussing on multiple travel mode usage, but without necessarily adversely affecting vehicular mobility. In a typical example, a four lane road (two lanes in each direction), with no median strip or bike lanes, is turned into a two lane road (one lane in each direction), with two bike lanes plus a median strip facilitating traffic turns. Despite the two fewer lanes for vehicle travel, vehicular mobility and flow can actually improve, if not remain unaffected, due to the designated bike lanes and the median strip reducing chances of conflict when vehicles make turns. Some studies (such as Tolford, Renne & Fields, 2014) have developed low-cost methods of holistic pedestrian safety evaluation relevant to Complete Streets initiatives. These methods are both cognisable of and adaptable to diverse situations due to their seeking a range of data relevant to traffic conflicts. For example, as well as pedestrian-vehicle crash statistics, the approach also considers pedestrian volumes and ages, diversity of activity in the pedestrian areas, presence of pedestrian generators (such as shopping areas, schools and bus stops), peak hour times, low income neighbourhoods, pedestrian safety priorities identified by residents and vehicle speed limits.

Dumbaugh and Li's (2011) call for research into how drivers and other road users adapt their behaviours in response to the built environment might have been heeded by a research team who recently studied how a sample of drivers, cyclists and motorcyclists described their experiences in negotiating a 7km route in Melbourne that included intersections, arterial roads, roundabouts and a shopping strip (Salmon, Lenné &Walker et al., 2013). The research team found the drivers, motorcyclists and cyclists exhibited markedly different situational understandings even when operating in the same road environments. Such differing situational awarenesses can create conflicts between these types of road user, particularly at intersections. For example, at intersections, drivers commonly focus their situation awareness on infrastructure aspects such as traffic lights, the lights' status and the area in front of their vehicle, whereas motorcyclists' and cyclists' situational awareness is strongly oriented towards other traffic and the behaviour of other road users. This could contribute to conflicts when riders manoeuvre themselves around intersections in areas that drivers do not focus on, such as the left and right sides of their vehicle. Likewise, drivers may not become aware of riders until they are just ahead of their vehicle. Overall, the research concluded that situation awareness is heavily related to the road environment in which the road users are operating, and that road and infrastructure design have a critical role in supporting situation awareness across different road users and in enabling different types of road user to relate to each other better.

A major UK review of literature on infrastructure and cycling (Reid & Adams, 2011) somewhat pre-empted Dumbaugh and Li because, while the review noted that cyclist casualties are primarily the consequences of human behaviour, it pointed out that this occurs in a context formed by infrastructure, law, culture and the behaviours of other road users. For example, large roundabouts are effective at maximising motorised vehicle traffic speed and flow through intersections, and in reducing the chances of severe crashes for motorists, however roundabouts remain especially hazardous for cyclists. Some cyclist-specific infrastructure treatments, such as painted cycle lanes and cycle advanced stop lines (or boxes) have shown only limited effectiveness in improving cyclist safety. Moreover, while providing segregated paths for cyclists has had some success in reducing cycling risks, this tends not to be the case where the segregated paths intersect with roads. Indeed, there is evidence that the risk to cyclists at such locations is not offset by the safety benefits of segregating them from motorised road users (Reid & Adams, 2011). Overall, the review (Reid & Adams, 2011) considered that the best approach to improving cyclist safety is to reduce motorised traffic speeds in conjunction with segregated pathways. However, this approach, in Dumbaugh and Li's view, would still not address the more fundamental issue: the tension between cyclist safety and traffic conflicts where the road environment allows cyclist pathways and motorised traffic to intersect.

Nonetheless, in recent years, much research on improving cyclist safety has centred around traffic conflicts. For example, Dutch research (Schepers, 2013) found that more collisions occur at intersections where the cyclist has right of way, but that the crash probability can be reduced if there are raised bicycle crossings at the intersection and if the cycle path approaches to an intersection are deflected between 2 and 5 metres away from the road. Cyclist crashes from traffic conflicts at intersections were also studied recently in Canada (Harris, Reynolds &Winters et al., 2013). It was found that intersections of two local streets had much lower risks than intersections between two major streets, but risks to cyclists were increased where roundabouts existed. The study noted that the increased risks could be attributed to the greater number of traffic conflict points attendant on roundabouts, with the two main types of crashes at roundabouts studied being due to collisions with motor vehicles where the cyclist was not seen, and single cycle crashes where the cyclist collided with infrastructure such as the kerb. The study also found that, while cycle tracks alongside major streets but physically separated from motorised traffic reduced collision risk, for local streets cycle tracks were safer when there was infrastructure that tended to divert motorised traffic away from using the streets having cycle tracks. Work in California (Nuworsoo, Cooper & Cushing et al., 2012) reported that other cycle track infrastructure such as cycle parking, route directness of the track, wide lanes for passing each other and traffic light phases for cyclists crossing a road are likely to increase usage of cycle tracks, thereby removing cyclists from regular roads and reducing the incidence of cycle/motor vehicle crashes.

Traffic conflicts involving motorcyclists have been studied in Australia (Allen, Day & Lenné et al., 2013). The most common conflict scenario reported in the 75 crashes studied was another vehicle turning into the path of a rider. Moreover, half of the crashes occurred at intersections and a fifth occurred on a curve or bend, while in 27% of cases it was calculated the rider was exceeding the speed limit. In the USA, a study by Schaffer, Heuer and Bents et al. (2011) aimed at identifying forgiving infrastructure for motorcyclists rather than aiming for reduced traffic conflicts involving them. However, the research team's approach identified the infrastructure through a consultation process involving discussion of traffic conflicts among highway design specialists and various motorcycle rider groups committed to improving motorcyclist safety. A similar traffic conflict consultation process was employed in a European scan of motorcyclist safety (Nicol, Heuer & Chrysler et al., 2012). Other cooperative European research (van Elsande, Feypell-de La Beaumelle & Holgate et al., 2014) concluded that the Safe System approach should be modified with respect to motorcycling by focussing on strategies that aim to avoid crashes (through reducing potential for conflict) rather than merely mitigating their effects (such as by forgiving infrastructure).

Vehicle technology is a key component of any holistic approach to improving traffic safety. The US National Highway Traffic Safety Administration (NHTSA) (2013) places importance on developing technological capability in vehicles to detect the presence of pedestrians and in avoiding collisions with them. The NHTSA also recognises the potential for traffic conflicts with pedestrians posed by quieter vehicles such as electric cars and hybrid models. In an ongoing project, Iowa University (Chrysler & Hamann, 2015) is also studying how vehicle drivers respond to pedestrian and cyclist behaviours, but from the perspective of developing and improving in-vehicle technologies that can warn drivers of a potential traffic conflict with a vulnerable road user. At the specific operational level, Kings County in Seattle (2015) is trialling turn warning technology on its public buses. The warning system is activated when a bus turns a corner, such that English and Spanish recorded voices can warn nearby pedestrians and cyclists with the message: "Caution, bus turning", accompanied by activation of an external strobe-light.

There is also European-based research into vehicle technology with potential to reduce conflicts with vulnerable road users. An extensive European Commission study (Hynd, McCarthy & Carroll et al., 2015) concluded that among the most worthwhile vehicle technologies for reducing vehicle and vulnerable road user conflicts are: intelligent speed adaptation, assistance to keep a vehicle in lane, and reversing systems that can detect the presence of vulnerable road users, particularly children. One specific project has involved assessing the impacts, usability and efficiency of various vehicle technologies on vulnerable road users in traffic scenarios that are critical for vulnerable road user safety (Scholliers, Bell & Morris et al., 2014). One type of critical scenario occurs when the vulnerable road user is poorly visible to a motorised driver, or is otherwise easily overlooked by the driver. The study concluded that technologies and systems that enhance the detectability and visibility of vulnerable road users are considered to have high potential to increase vulnerable road user safety. For example, blind-spot detection systems in trucks, and devices (possibly using smartphone technology) allowing communication between motorcycles and larger vehicles, show much promise in reducing truck-cyclist and motorcyclist-vehicle conflicts respectively (Adminaite, Allsop & Jost, 2015; Scholliers, Bell & Morris et al., 2014). The European Union is urging its member states to change their legislation to permit the re-design of driver cabins in heavy vehicles to afford greater visibility of vulnerable road users (Adminaite, Allsop & Jost, 2015). Also advocated by the EU (Scholliers, Bell & Morris et al., 2014) are intelligent pedestrian traffic signals (as in the earlier GLA example (GLA, 2014)).

Discussion

Collectively, the examples above tend to be of studies that do not aim to simply identify the safety benefits or otherwise of various forms of infrastructure and vehicle technologies. Rather, the studies aim for a better understanding of the contextual nature and causes of traffic conflicts involving vulnerable road users in the first place, and then looking at how infrastructure and vehicle technology can serve to minimise or eliminate those conflicts. This is important because vulnerable road users are receiving smaller benefits than vehicle occupants from recent road safety improvements (ITF, 2014), which also suggests that Safe System thinking towards vulnerable road users is not as well developed as it is for vehicle occupants. Just as important, however, is that an emphasis on minimising or eliminating traffic conflicts, obtained through a better understanding of their contextual nature, particularly for vulnerable road users, has much potential to contribute to the Safe System thinking and conceptualisations that now underpin our whole approach to road safety. The emphasis should urge Safe System models to extend beyond their traditional focus on susceptibility to crash forces and systems that are forgiving, to provide for a greater recognition of the vulnerability of pedestrians, cyclists and motorcyclists in the Safe System model, as highlighted in many recent traffic conflict studies and in best practice principles for urban design.

Moreover, in seeking a better understanding of what should constitute a Safe System for vulnerable road users, it needs to be acknowledged that pedestrians, cyclists and motorcyclists have different experiences of traffic conflict and may well need different requirements in terms of a Safe System.

Conclusions

Collectively, vulnerable road users need a Safe System that extends its core principles currently acknowledging tolerance of human error and susceptibility to crash forces, and hence implementing a forgiving system, to embracing a new core principle, that of recognising the need to eliminate or minimise the potential for traffic conflict. Such an expanded direction in Safe System thinking, while of particular benefit to vulnerable road users, would turn out to be of benefit to all road users.

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Contributed articles

Road Safety Policy & Practice

Automated vehicles supporting "Towards Zero" Initiative

Carl Liersch

ACRS Member, Melbourne, Australia

Corresponding Author: Carl Liersch, Engineering & Business Development Manager, Robert Bosch (Australia) Pty. Ltd, Carl.Liersch@au.bosch.com

Key Findings

1. First public demonstration globally by Bosch of an SAE Level 3 automated vehicle.
2. Automation, driver monitoring, HMI, and connectivity concepts presented.
3. Highly automated vehicle prepared in Australia using local and global resources.
4. Bosch Australia are preparing for a future when HAD vehicles are mainstream.
5. Bosch Australia supporting community discussions for a "zero accident" future.

Abstract

Many of us talk about a future where there are zero accidents and all vehicles are automated or driverless. It sounds attractive but how easy is it to automate a vehicle that is suitable for all driving conditions? What are the considerations we must engineer into such a vehicle? This paper explores some of the technology and highlights many of the challenges that are being confronted by Bosch in the drive to achieve a zero accident future.

Keywords

Automated Driving; Bosch; ITS World Congress

Glossary

HAD – Highly Automated Driving
ITS – Intelligent Transport Systems
SAE – Society of Automotive Engineers
TAC – Traffic Accident Commission
ABS – Antilock Braking System
TCS – Traction Control System
ESC – Electronic Stability Control

EPS – Electric Power Steering
MRR – Mid-Range Radar
SVC – Stereo Video Camera
DMC – Driver Monitoring Camera
NRC – Near Range Camera
MPC – Multi-Purpose Camera
USS – Ultrasonic Sensor
Lidars – Light Imaging Detection and Ranging Sensor
HMI – Human Machine Interface

Introduction

Assuming that most road fatalities and injuries are the result of a failure by a driver to concentrate adequately on the task of driving their vehicles under the given conditions in which they happen to be at the time of the "incident", the following question must be: Can automation of a vehicle lower or remove the risk of any "incident" occurring? If the implemented automation completes its tasks to an adequate level then logically the answer must be "yes".

By an adequate level we mean that the vehicle must complete the tasks to the same level as a human driver when they are concentrating correctly and actively avoiding any incident from occurring. These tasks that are being referred to include all of the seemingly mundane tasks that are undertaken by vehicle drivers whenever the vehicle is in motion. This could be during a short drive to work, or to the shops, or to school, or wherever else the driver may travel, every day of every week of the year. Backing out of the driveway, looking left and right while indicating and operating the accelerator, brake and maybe the clutch if a manual gearbox is in use. Noticing that the vehicle up ahead is adjusting its own lane position and thoughit hasn't yet indicated, is likely to turn right at any moment. Recognising that your neighbouringvehicle has a driver distractedby the behaviour of children in the back seat, and that the car behind you is clearly in a hurry and wants to overtake you, demonstrated by the way they have come up behind you so quickly and are sitting now only scant meters behind your vehicle as you try to keep to the variable speed limit.

As human drivers we are constantly adapting to an environment around us that is continuously changing and requiring a high level of observation and decision making while operating a significant piece of heavy machinery – your vehicle. Trying to automate these tasks, which we as humans are able to complete without incident most of the time, is not to be underestimated. Good automation of vehicles requires that we not only deal with the problems with which we as humans fail from time to time, but also with all of those other tasks that we do successfully complete (albeit with varying degrees of skill) on all other occasions.

Robert Bosch (Australia) Pty. Ltd. has been researching and developing solutions to the not insignificant challenge of zero accidents for many years now. It is not a challenge that can be completed in one fell swoop, but it requires many steps along a long path that also slowly allows human drivers to adapt to the changing levels of automation in their vehicles. Simple features such as automatic windscreen wipers, automatic transmissions and self-locking doors are early levels of automation in a vehicle that takes some of the increasing load of decision making off the driver, allowing the driver to concentrate on the important tasks of steering and speed control. At another level the complexity of contemporary vehicles has been increasing as the automotive industry strives to increase safety and implement other desired functionality into vehicles for public use.

But is the world ready for this level of technology? Are the legislative rules and regulations in place for vehicles being driven without hands on the steering wheels?

In October 2016 global automotive supplier Bosch presented an SAE level 3 Highly Automated Driving vehicle at the ITS World Congress in Melbourne. A right hand drive vehicle was prepared in Australia by a local team of Bosch engineers leveraging the skills and knowledge available globally in the Bosch organisation(see Figure 1), and supported by financial contributions from the Victorian Government through the TAC. For Bosch globally this was the first time that we had publicly demonstrated a vehicle of this level and complexity, presenting not only a vehicle that could supervise its own automation system, but also demonstrating concepts for driver monitoring and a human machine interface. This was an opportunity for members of both the industries involved in this sophisticated technology and the general public to experience how the technology may present itself to them in a vehicle, and to formulate informed opinions that will support the debates required for establishing legislative rules and regulations. It was also an opportunity for Bosch to gauge the reactions of the passengers to the implemented concepts.

Figure 1. Bosch Highly Automated Vehicle and Team

What does it take to automate a vehicle?

At a basic level, turning a modern vehicle into an automated vehicle is not so difficult. An electric power steering system allows for directional control, an interface to the drivetrain system allows for speed control, and ESC in the vehicle gives you the ability to generate braking pressure. The complexity really begins when one starts to specify the "use" cases: i.e. Where would you like the vehicle to go? How fast would you like the vehicle to travel along that route? What precision of steering control would you like? For what types of obstacles do you want the vehicle to actively decelerate or avoid? What is the environment like in which you would like the vehicle to travel? Additionally each of the above systems needs to be integrated with each other so that priorities can be set. Under what circumstances does steering take priority over braking, or should they both occur simultaneously under some or all conditions? What level of redundancy do we need so as to be robust in all conditions should some part of one of the systems fail? The challenges are many and varied but in order to better understand the problems that need to be solved let's first begin with the environment.

Environment

In order for a vehicle to deal with all of the challenges that we can imagine for an automated vehicle we need to first understand what is happening around the vehicle. Is there anything close to the vehicle? Are there objects moving towards or away from the vehicle, longitudinally or laterally? What objects do we need to be concerned about? Is anything smaller than a tricycle okay to ignore? Should we consider the density of the object? Does the object have a shape that we can identify and classify? Are we on a known road and if so, does that road have clear line markings so that we know where the car should be placed on the road? Do the local road rules require the car to drive on the left or the right hand side of the road? How can we robustly detect all of the above conditions, and others besides, before we even begin automation of the vehicle?

Bosch's approach to this has been to develop sensing solutions for as many of the use cases as we can imagine(see Figure 2), which were implemented on the ITS World Congress 2016 Bosch demonstration vehicle.

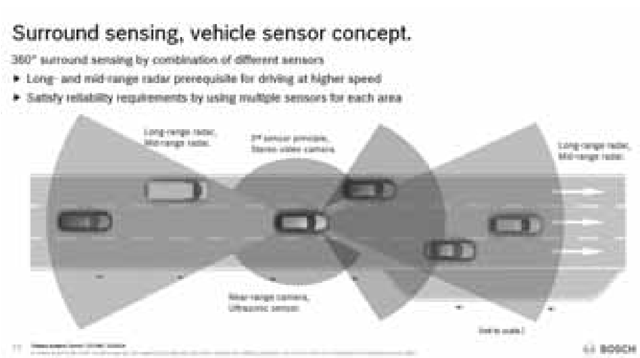

Figure 2. Bosch sensing solutions

Long range radars are facing forward and backward to allow the vehicle to sense as far ahead and behind as possible; up to 250 metres. Given that in some countries the speed limit is substantially higher than in Australia this gives a relatively early opportunity for detection of situational concerns.

A family of mid-range radars (MRR) are placed strategically around the vehicle. Typically this means one facing forward (MRR Front), one facing rearwards (MRR Rear), and one at each corner of the vehicle (MRR Corner). The features of these radars vary with regard to sensing distance and field of view, ranging from 30-150 metres and 12-150 degrees respectively.

Ultrasonic sensors (USS) are important for when the vehicle is manoeuvring at slow speeds. The latest generation is now able to measure out to six metres from the vehicle.

Light Imaging Detection And Ranging Sensors (or lidars as they are commonly known), nominated as the third sensing principle in Figure 2, are able to scan an object at a much higher density than a radar, giving a far more detailed view of an object than a radar would. These are also placed around the vehicle in a similar fashion to radars.

A range of vision systems are also used in the form of stereo video cameras (SVC), multi-purpose cameras (MPC), and near range cameras (NRC). In the same way that the radars vary in performance so do the cameras. The one big advantage of cameras is that they can see variation in colour. A good example is being able to see line markings on a road (something none of the other sensors can do). They are also able to recognise road signs including speeds (60km/h or 80km/h) and commands such as "STOP".

One might ask why we need lidars, radars and cameras to sense the environment around the vehicle. The answer is simple – definition, disparity and redundancy. We need to create a comprehensive and unambiguous 360^{o} environment model. While each of the "sensors" might be able to detect the same objects, they note different features about the objects. Fusing this information together can create a far better understanding of what the detected object might be, but they can also be used to correlate with each other the existence of an object. For example, a lidar might detect dust as an object whereas the radar might well not detect it at all. The camera may be covered with dust and so therefore be of no use at that time. Now comes the tricky bit. What should the vehicle then do?

Driver Monitoring

Even though the vehicle may be automated the driver still needs to be considered. They are the one who will most likely define the destination and potentially the desired route, and in a level 3 vehicle as demonstrated at the ITS World Congress 2016, will need to be in control in non-automated driving situations. Additionally the driver can also be unpredictable. Will they be able to take over the driving task if needed? Are there times when the driver should not take over control? Is the driver impaired in some way or perhaps unwell?

Bosch has been developing driver monitoring and support functions for well over a decade now. In many vehicles we are now able to reliably detect if the driver is drowsy, but in an SAE Automated Level 3 or 4 vehicle we have to take this to a higher level, as in these vehicles the need will arise where the driver must be able to take control. We therefore want to detect the identity of the driver so as to be sure they are a registered driver of the vehicle. Are they awake or distracted? Are they impaired in some way such that they cannot, or should not, take control of the vehicle?

The demonstrated solution utilises a small specialised camera mounted behind the steering wheel with software that is able to detect both micro-sleeps and when the driver looks away from the road ahead for any more than a defined period during non-automated driving situations. In these cases audible warnings are presented in the vehicle designedto bring the driver back to the driving task should they need to be in control.

Decision Making

Consider the constant decision making that you do as a driver of a vehicle every second of your journey. Some decisions happen almost sub-consciously (think about the constant steering adjustments you make to maintain your vehicle position within a lane on the road), whilst other decisions require clear planning and execution (for example deciding which route to take to a certain destination and navigating your way there). The challenge for an automated vehicle is to execute the plan that you have given to the vehicle in a way that is safe, smooth, efficient, and appears to be entirely logical to you as the driver.

The developers of these systems need to cater for all driving scenarios and situations. Given that there are always driving scenarios that are somehow neglected, they need to also ensure that the vehicle can learn from its own experiences in the same way as humans do. What this means is that we are entering the realm of artificial intelligence to help us deal with all the potential situations and scenarios that exist in every day driving. Can the vehicle learn about regular driving routes and scenarios? Can it learn the driver's preferences and driveaccordingly? Can the vehicle adapt to unforeseen behaviour by other users of the roads in a manner that the driver might expect?

Bosch has been working together with selected universities and institutes in the field of robotics, artificial intelligence and deep machine learning for a number of years now. The advances in these fields of technology are racing forward at an exciting rate and show great promise for dealing with the tasks that may appear to us as drivers of vehicles as somewhat mundane and simple but are in fact relatively complex.

Verification and Validation

The number of "use" cases for automated vehicles to negotiate are enormous. To give you some idication of the challenges facing developers, Bosch have a catalogue of tests for ABS, TCS and ESC that run sometimes into the thousands, depending on vehicle variants and complexities. Just combining another system to these aforementioned ones, such as Electric Power Steering (EPS), multiplies the combination of tests at least ten-fold. What this demonstrates is that each time another system is added the complexity of testing is multiplied. Because we combine multiple systems for highly automated driving the number of test cases could be in the millions. Testing against all of these use cases, even in simulation, requires significant time and effort and is simply not possible without considering new and novel approaches to how an automated car can be proven to be adequately tested prior to release for the public to drive. As shown in Figure 3 below, the estimated expenditure in effort for validation will increase by a factor of 10^6 to 10^7.

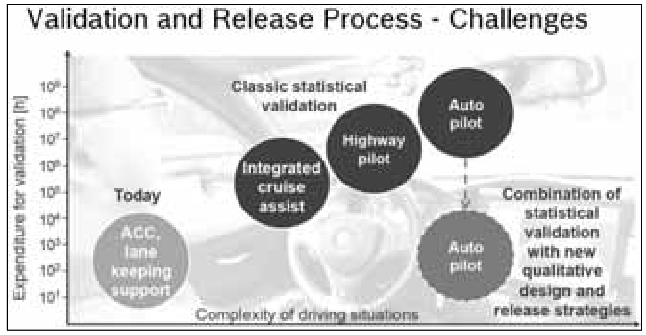

Figure 3. Verification and validation effort

One way for Bosch to deal with this challenge is to make each component in each development vehicle connected to the Bosch Cloud. By implementing this form of connectivity a big data approach can be utilised. Every moment that the vehicle is moving can be logged and used to statistically define both the durability concerns for the hardware in the vehicle, and scenarios with which the vehicle needs to deal with often, or seldom, and should be required to prioritise.

Human Machine Interface (HMI)

The HMI in a car is one of the most difficult features to engineer into a vehicle. No two people will ever agree on exactly how a particular solution should be engineered for use by the public. The HMI for an automated vehicle is very important. It must be intuitive and simple to use. It must give information to the driver in a way that is logical and unambiguous.

What we demonstrated at the ITS World Congress 2016 was just one concept developed by Bosch engineers and researchers. Two main interfaces were implemented: 1. A central screen that provides visual and audible information and cues and; 2. A steering wheel with HAD activation buttons and visual cues as shown in Figure 4.

Figure 4. Human Machine Interface concepts

Bosch is not suggesting that this is the way that all companies should implement their HMI solutions, but it is one approach that we think is possible for Level 3 & 4 vehicles. Clear instructions are given on the central display with requests for takeover of control well before the end of the section of road designated for automated driving. Lights on the steering wheel change colour depending on the state of the automation. In this case we used blue for manual control, white for automated control, and red for when the driver is requested to take control back from the automation.

Legal Issues

Through a process of consultation, discussion and risk management, limited permission was given by VicRoads for Bosch to drive our automated vehicle on public roads. Many of the discussions centred on understanding what risks may exist with the Level 3 HAD solution proposed by Bosch and how those risks were to be mitigated. Some of the requirements Bosch put in place included allowing only specifically trained drivers behind the steering wheel when vehicle automation was to be used, and then only for a limited period at any one time up to a defined total number of hours in any one day. Bosch needed to provide evidence of sufficient liability insurance in the case of an accident, and agree to provide recorded vehicle data in the case of an accident.

Discussion

While prototype vehicles can be catered for through specific permissions and requirements being put in place, all of this work did raise questions with regard to production vehicles and how the various states and territories in Australia might deal with the legal issues of allowing automated vehicles on the roads. Currently each of the Australian states and territories have either no requirements to date other than the existing regime of legislation dealing with the vehicles that are sold in Australia, or they have their own defined solutions. Fortunately at this time the requirements seem not to be too onerous for developers of solutions like Bosch. There is however a need to harmonise the guidelines and regulations before Australia is confronted with production vehicles capable of SAE level 3, 4 and 5 automation. The National Transport Commission (NTC) are currently developing national guidelines which we expect will support commonality in acceptance of automated vehicles into each of the states and territories.

Based upon the many discussions with members of the public to date, there are sections of the community who feelvery sceptical about HAD vehicles and how safe they might be. Equally we've met many individualswho are very enthusiastic about a future with HAD vehicles and how they believe their lives will change as a consequence. In either case, what has become clear to us is that public education with regard to how to behave around HAD vehicles is likely to be necessary. What should a driver of a non-HAD vehicle expect from HAD vehicles? What knowledge should a driver of a HAD vehicle have before they start activating the HAD system within their new HAD vehicle? And perhaps most importantly for the public, who takes responsibility in the event of an incident involving a HAD vehicle driving in HAD mode?

Fortunately the engineering solutions to the challenges of bringing an SAE level 3 or 4 vehicle into production are still being worked on and we have a little time to figure out answers to the questions above. Bosch is committed not only to the engineering solutions surrounding HAD implementation in vehicles, but also to helping the government agencies involved in the legal questions and difficulties, and to supporting public education in understanding the details of HAD vehicles and how they will affect our lives into the future.

Conclusions

SAE level 3 and 4 vehicles will soon be available in the vehicle showrooms. It may only be a few years before the first vehicles become available to the public where hands-off, unsupervised driving is possible on selected roads around the world including in Australia and New Zealand. The question that remains is not how willing we are to embrace the technology, but how willing we are to embrace the challenges that this technology will bring to our society.

Bosch are working on the technological solutions, and are demonstrating the such concepts outside of the automotive industry so as to develop the engineering skills locally in Australia in preparation for a future when HAD vehicles are mainstream. Bosch is also encouraging discussion and debate within the wider community to aid both community acceptance and readiness for this technology, and to receive feedback so that we can support development of the best solutions possible as we work towards a "zero accident" future.

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iRAP road and design assessments and outcomes: A case study from Moldova

Steve Lawson[1], Alaster Barlow[2], Chaim Poran[3], Hakob Petrosyan[4], Marko Ševrović[5]

[1] *EuroRAP, Worting House, Basingstoke, RG23 8PX, United Kingdom*

[2] *AECOM, 20 Colmore Circus Queensway, Birmingham, B4 6AT, United Kingdom*

[3]*Millennium Challenge Corporation, 1099 14th St., NW, Suite 700, Washington, DC 20005, USA*

[4]*Challenge Account, Moldova, 21, N. Iorga street, MD-2012, Chisinau, Republic of Moldova*

[5]*University of Zagreb, Faculty of Transport and Traffic Sciences, Vukelićeva 4, 10000 Zagreb, Hrvatska / Croatia*

Corresponding Author: Steve Lawson, EuroRAP, Worting House, Basingstoke, RG23 8PX, United Kingdom, steve.lawson@eurorap.org, +44 1256 345598.

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Key Findings

- This is a before and after study of reconstruction of 93km of the M2-R7 in Moldova.
- It is estimated that around 300 fatal and serious injuries will be reduced over 20 years.
- Roadside protection, intersections and village quality have been improved.
- The percentage of relevant road sections rated 3-star or better has increased.
- An iRAP Safer Roads Investment Plan and safety audit show further savings possible.

Abstract

This work, supported by the Millennium Challenge Corporation, assessed the safety of the road infrastructure of a 93km section of the M2-R7 in Moldova in 2010 and 2015, before and after rehabilitation. The iRAP Star Rating with a Safer Roads Investment Plan guided provision of more than 22km of footway (sidewalk), a doubling in the number of pedestrian crossings to more than 50, installation of 12.3km of safety barrier, improvements in the quality of curves, the overall quality of the road surface, delineation and enhancement in the quality of intersections. Prior to upgrading, the safety rating of the road for pedestrians was poor (84% of the road rated only 1- and 2-star) and, for vehicle occupants, the road was predominantly 1- and 2-star (87%). Since reconstruction, the Star Ratings have improved. The percentage of the road rating 3-star and above has increased by around 30 percentage points for pedestrians, cyclists, motorcyclists and vehicle occupants. The post-construction Road Safety Audit by AECOM includes recommendations for improvements at intersections, in villages, on roadsides and for some measures related to the route. The pre-construction EuroRAP investment proposal showed that, for an overall package of safety countermeasures, there would be a reduction of around 300 killed or seriously injured casualties over 20 years, with a Benefit Cost Ratio approaching 4, a saving of almost a quarter of casualties on the road had there not been upgrading.

Keywords

infrastructure, star rating, investment, benefit-cost

Introduction

In 2010 EuroRAP was involved in the safety assessment of 93km of the M2-R7 in Moldova prior to the upgrading work funded by Millennium Challenge Corporation (MCC). The route runs centrally, north-south, from near Moldova's border with Ukraine, reaching halfway to the capital, Chisinau. The EuroRAP work provided a "Star Rating" for the safety of this road for four road-user groups and showed that, for vehicle occupants, the road was predominantly 1- and 2-star (87%) and that, for pedestrians, 84% rated 1- and 2-star. A secondary part of the assessment was to provide a Star Rating from the design plans provided by URS Corporation (formerly United Research Services) and assess the likely character of the improved road. The M2-R7 upgrade and rehabilitation was designed to reduce transportation costs and increase safety, commerce, access and opportunity through the rehabilitation of an existing 93km road segment. Savings would include vehicle operating costs and time for passengers and goods and reductions in road maintenance costs.

The aim of this paper is to compare the original Star Rating and Star Rating from Design road safety assessment results produced during 2010-11 with post-construction assessment results for the recently completed upgrades. It included a survey of speeds on the road and a Road Safety Audit of selected locations so as to maximise learning opportunities and provide opportunities to generalise to other projects.

Improvements made to the M2-R7 in Moldova

The pre-construction EuroRAP investment proposal showed that, for an overall package of safety countermeasures, there would be a reduction of around 300 killed or seriously injured casualties over 20 years, with a Benefit Cost Ratio approaching 4, a saving of almost a quarter of casualties on the road had there not been upgrading.

The quality of the M2-R7 was substantially improved with many enhanced features. This included widespread use of higher standards of roadside protection, the improvement of many intersection and improvements to the ambience and visual quality of the villages and in provision for pedestrians. The following upgrades were made to the M2-R7:

- All existing roadside barrier was removed. This was previously of a very poor standard and quality. 12.3km of barrier was installed (Figure 1).
- More than 22km of sidewalk has been reconstructed or constructed.
- There has been a doubling in the number of village sections with pedestrian crossings to around 50.
- Improvements in the quality of curves, the overall quality of the road surface, delineation, enhancement in the quality of intersections (Figure 2) and greater consistency in the width of lanes, now almost exclusively recorded as “wide”.

The iRAP Star Ratings for the M2-R7 generally improved (Table 1). The percentage of the road with 3-star and above for vehicle occupants, motorcyclists and bicyclists all increased by around 30 percentage points. Due to the large distances between villages, there is very limited pedestrian activity on these road sections. Therefore, only the pedestrian activity in villages where 50km/h and 30km/h speed limit were present was rated. If any pedestrians are present on sections between villages, some will choose to walk on unpaved shoulders, on the carriageway, on parallel agricultural ways or on informal footpaths where they exist.

Figure 1. (a) Uncontrolled and unmarked 3-arm intersection “before”; (b) Well-designed and signed roundabout “after”.

Figure 2. (a) Poor quality markings and barrier “before”; (b) Improved markings and protection “after”.

Table 1. Star Ratings of before upgrades (B) and after upgrades (A) and the difference (D)[a]

Star Rating	Vehicle occupants			Motorcyclists			Pedestrians [b]			Bicyclists		
	B	A	D	B	A	D	B	A	D	B	A	D
5	0%	0%	0%	0%	0%	0%	0%	8%	8%	0%	0%	0%
4	0%	0%	0%	0%	0%	0%	0%	19%	19%	0%	1%	1%
3	13%	37%	24%	5%	33%	28%	67%	45%	22%	13%	45%	32%
2	17%	46%	29%	20%	28%	8%	24%	28%	4%	13%	50%	37%
1	70%	16%	54%	75%	29%	46%	8%	0%	8%	75%	3%	72%
Total	100%	100%	0%	100%	100%	0%	100%	100%	0%	100%	100%	0%

[a] In addition to the M2-R7, three short sections of rehabilitated road were rated – the L110 at its intersection with the M2 (1.3km,– this scored 3-star for vehicle occupants and motorcyclists, 2-star for bicyclists and 1–star for pedestrians assuming a 50km/h speed limit), the R14 north from its intersection with the M2 (1.8km – scoring 3-star for all road-users other than pedestrians (1-star)) and the northern extension from the M2-R7 to the Soroca Fire and Rescue Station entrance (0.5km – scoring 3-star for all users).

[b] Pedestrian activity is predominantly in the village areas (where 50km/h and 30km/h speed limit present) and only these areas are reported on here. Percentages may not sum to 100 because of rounding.

Results can be summarised as follows.

- The percentage of road rated 3-stars or better for vehicle occupants increased from 13% to 37%.
- The percentage of road rated 3-stars or better for motorcyclists increased from 5% to 33%.
- The percentage of road rated 3-stars or better for pedestrians in villages increased from 67% to 72% (with a notable increase in 4-star and 5-star provision (from none to 27% in total)).
- The percentage of road rated 3-stars or better for bicyclists increased from 13% to 46%.

The analysis shows that if speed compliance were improved, there would be a substantial improvement of the Star Ratings for pedestrians in urban areas and for vehicle occupants in rural areas.

Speed survey

The level of risk of death or serious injury on a road is highly dependent on the speed at which traffic travels. iRAP policy is that risk assessments are made using the “operating speed” on a road. Operating speed is defined as being the greater of the legislated speed limit or the measured 85th percentile speed. The posted speed limits for the M2-R7 were determined by the design teams in consultation with the traffic police and village mayors as part of the design process.

Rather than measure speeds at static sites along the M2 using a parked vehicle and traffic camera it was decided to work with the Moldova traffic police in collecting data from a moving unmarked police car. Trials using a parked car at two static locations proved unsatisfactory – the presence of the vehicle adjacent to the carriageway alerted drivers to the presence of the speed survey and they in turn warned oncoming drivers to reduce their speed. The EuroRAP team therefore arranged with the Moldova police to use their equipment in an unmarked police car moving in the traffic stream to record the speeds of all oncoming vehicles in the journey described above, along the entire surveyed length of the route.

Photographs from this survey were then assessed and entered on a database noting the speed limit, vehicle type and the highest speed of any recorded for each vehicle photographed (where more than one image per vehicle was taken). If several images were taken of a single vehicle in a village location, then any available reading on a 30km/h section was used in preference to that on a 50km/h section. The speed of 21 vehicles in the sample (less than 5%) may have been limited to some extent by vehicles ahead of them, the overall result presented below therefore possibly understating the travelled speeds.

The speed survey data set included a sample of 466 (391 car/van/mini-bus, 75 truck) taken during a drive from Sarateni to Soroca (M2) and the R7 to Drochia junction. It included an additional double run (whilst driving in both direction within the village) in Prodenisti (57 observations). These results are presented in Table 2.

Mean speeds in the villages were typically lower than on the rural road sections for both categories of vehicle (cars/vans/minibuses versus trucks) although the mean speeds of (the small sample of) trucks in the 30 and 70km/h limits differed little. The 85%ile speeds of the sample of truck speeds on the 30km/h section was higher than the sample of cars, vans and minibuses. For cars, vans and minibuses, 85%ile speeds on the rural sections were more than 15km/h higher than the posted speed limit. In the villages, 85%ile speeds for vehicles were more than 25km/h and 40 km/h respectively above the posted limits of 50km/h and 30km/h for cars etc.

At the 30km/h speed limit, all vehicles exceed the limit, at 50km/h the great minority exceed the limit, but at the 70km/h and 90km/h limit there is a more even split. It is estimated that speeds have increased on substantial part of the M2-R7 in both village and rural sections by around

Table 2. Mean speed and 85%ile speed by vehicle type at various posted speed limits on the M2-R7 (km/h)

	Rural				Villages			
	Speed observations outside villages on M2-R7, Sarateni-Drochia junction				Speed observations in villages on the M2-R7, Sarateni-Drochia junction			
	Car/van/ minibus	Truck	Car/van/ Minibus	Truck	Car/van/ minibus	Truck	Car/van/ minibus	Truck
Posted speed limit	90	90	70	70	50	50	30	30
Sample size	141	31	45	8	122	22	83	14
Mean speed	89	77	72	58	61	51	56	59
85%ile speed	107	97	88	70	77	60	72	81
Mean speed above speed limit	-1	-13	+2	-12	+11	+1	+26	+29
85%ile speed above speed limit	+17	+7	+18	0	+27	+10	+42	+51

10km/h. The 30km/h speed limit in place in villages, notably around pedestrian crossings, is ignored. More needs to be done to reduce speeds on entry to and when travelling through the villages.

Road Safety Audit

The Road Safety Audit of 9 sites on the M2-R7 identified items that require attention and remedial action. Many of the following recommendations and issues have been responded to by the Millennium Challenge Account Moldova.

At intersections – there were some inconsistencies of design layout and of signing, unsealed shoulders and debris on road, excessive vegetation around signing.

- In villages – location of some pedestrian crossings could be improved, give-way markings at some intersections were required, there was the potential for greater use of curbed refuge islands, there were occasional inappropriate positioning of objects on footways, uninterrupted sections with potential for high speeds, use of fishtail, unprotected or ramped barrier ends.

- On roadsides – as well as the deficiencies noted above, greater protection of a bridge structure was required.
- In some large areas where movement is controlled by road markings alone, there was insufficient deflection and advance warning was inadequate.
- Route issues – there were concerns about barriers, advance warning at intersections and of lane-loss (reduction from two lanes to one), and retention of the original signing causing information inconsistencies.

Safer Roads Investment Plan

The iRAP ViDA software provided a Safer Roads Investment Plan based on the data collected during the "after" survey. This proposes additional countermeasures and indicates that there are still opportunities to enhance safety on the road. An economic analysis of safety countermeasure options identified countermeasures in this enhanced safety package of almost 80m Moldovan Leu (about 4m USD) that could potentially save almost 300 fatal and serious injuries over 20 years, a reduction of more than a third (36%) of those likely to occur in that period. This would save approximately 180m Moldovan Leu (about 8.9m USD) in crash costs with a BCR of 2. Countermeasure costs are approximate and vary according to particular locations.

The improvements include: installing or improving roadside barriers, shoulder rumble strips, central hatching, clearing roadside hazards and shoulder sealing. Measures identified in other parts of the study involve reducing speeds, upgrading and extending safety barriers; and installing village "gateway" treatments.

Future recommended actions

Based on the assessment, the following recommendations are made:

- Enforce the speed limit at priority locations by means of average speed cameras, notably in the villages.
- Review the recommendations of the post-assessment Safer Roads Investment Plan and consider which investments may be a priority.
- Act on the recommendations of the Road Safety Audit at the specific locations recommended.
- Follow up those elements from the Road Safety Audit that are likely to be repeated at various points on the network. In particular, assess the location and design of barriers, notably those with ramped, unprotected or fishtail terminals.

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Perspective/Commentary on Road Safety

Tragic failure of a road system – an Australian example

Lori Mooren, PhD
Research Consultant, Transport and Road Safety Research Centre, University of NSW, Sydney, NSW, Australia
Corresponding Author: Lori Mooren, lori.mooren@unsw.edu.au, +61 412 888 290.

Key Findings

- Globally, road and traffic systems are providing the conditions to allow some 1.25 million people to die every year.
- The application of root cause analysis methods can identify systemic factors in road injury.
- Some road authorities are not embracing a safe system approach to road safety.
- People are generally complacent about the continuing road trauma crisis.
- A louder community voice is the key missing element in the struggle to eliminate road deaths and injuries.

Keywords

Safe system, systemic injury causation analysis, community demand

Introduction

The first recorded automobile fatality occurred in Ireland, in 1869 (Fallon & O'Neill, 2005). The event was described as a "public scourge and a private tragedy." The coroner was moved to say, "This must never happen again." But then in 1899, Henry Bliss was killed when struck by a taxi in the United States while alighting from a streetcar.

Later, in post war 1947, J S Dean wrote a book entitled, "Murder Most Foul: a study of the road deaths problem." He concluded that "The 'reconstruction of Britain' will indeed be a dismal failure if it includes as a permanent feature of the national life the killing and maiming of a quarter of a million, or more, of persons every year on the roads…there is no reason for failure…all that is needed is the will to act." (Dean, 1947)

In 2004, leading road safety researchers (Peden et al., 2004) estimated that road fatalities and serious injuries will rise by 65% by the year 2020, that deaths resulting from road crashes will exceed deaths from HIV, malaria and tuberculosis, and is predicted to become the third leading contributor to the global burden of disease and injury. In its Global status report on road safety 2015, the World Health Organisation (WHO) reported that the worldwide number of traffic deaths has plateaued with 1.25 million people dying each year on the world's roads (World Health Organisation, 2015).

One becomes acutely aware of the magnitude and threat to the community when looking at the total number of deaths that occur in any country resulting from a traffic crash, and comparing that number to the number of deaths resulting from all the wars and disasters its citizens have suffered. For example, the total of fatalities Australia has suffered in all wars to date is around 103,000 of which only 36,000 occurred since 1925 (Australian War Memorial, 2013). Added to this number should be the number of Australians who have died as a result of natural and human created disasters (fires, bridge collapses, bombings, etc), being only around 1000. This total can then be compared to around 171,000 fatalities total resulting from all road crashes since records started in 1925. This is almost double the number over a shorter period.

The figures contrast in a similar way for the USA. Around 1.8 million road fatalities to date have been recorded since only 1966 (US National Center for Statistics and Analysis, 2004), compared to around 1.4 million fatalities from all wars, including the US civil war and disasters that include heat waves, hurricanes, floods, bombings, etc. (White, 2010). In the year 2000, fewer than 4,000 people were killed in the Twin Towers terrorist attack in New York, but more than 40,000 Americans are killed in road crashes *every year*. Yet US Government attentions to anti-terrorist initiatives far outweigh the attention to road safety in that country. Indeed, when the casualties of wars and disasters are compared to the casualties from traffic crashes for just about any developed nation, it becomes obvious that traffic crashes are a much greater risk to the health and well being of society.

Moreover, the incidence and severity of road crashes is somewhat more predictable and preventable than are other forms of injury causation. Much more so than natural disasters, where magnitude and location are difficult to predict, and wars, where injury is intentional, road trauma is known to be caused by certain characteristics of roads, vehicles and behaviours – all of which can be ameliorated.

From the early 1990s researchers and practitioners in the Netherlands sought to find ways to dramatically reduce road deaths. In recognition that human errors play a large part of road injury risk, Dutch Government stakeholders, at national, provincial and local levels, committed to take a planning and design approach to developing a sustainably safe road traffic system. The strategy emphasises the application of three safety principles in a functional hierarchy of the road network – functionality, homogeneity and predictability (Wegman et al, 2005). The challenge is to reorganise the road network into roads with *flow* functions, *distribution* functions and *local access* functions and to manage speeds, types of vehicles and road users' behaviours in accordance with the safety parameters that would enable people in the road environment to remain unharmed. The objective was to provide a road traffic system that is adapted to the capabilities and limitations of human road users. The design reference is the human being, considering human error and human physical tolerance to mechanical forces.

The passage of the Vision Zero legislation by the Swedish Parliament in 1997 was underpinned by a strong ethical basis for road safety. The Swedes took the bold position that it is unacceptable to trade safety for mobility in the road environment. One key premise of this new approach was that *"…the speed limits within the road transport system should be determined by the technical standard of vehicles and roads so as not to exceed the level of violence that the human body can tolerate"* (Tingvall and Haworth, 1999).

The strategy underpinning the Vision, is one of taking a quality management approach to managing safety in the road transport system. Road system designers, vehicle manufactures and those who employ professional drivers all have roles to play in developing and managing an inherently safe road transport system. Road infrastructure and vehicles must be designed to protect human bodies from the risk of injury, while the road users themselves be encouraged or forced to use vehicles and roads safely. Moreover, if the system is found not to meet these standards in any way, the defect must be corrected by the designers. The principles of Vision Zero state:

1. *'The designers of the system are ultimately responsible for the design, operation and use of the road transport system and thereby responsible for the level of safety within the entire system;*
2. *Road users are responsible for following the rules for using the road transport system set by the designers;* and
3. *If road users fail to obey these rules due to lack of knowledge, acceptance or ability, or if injuries occur, the system designers are required to take necessary*

steps to counteract people being killed or seriously injured. (Tingvall and Haworth, 1999)'

Throughout the 1990s, Australian States were actively pursuing road safety based on analysis of crash injury data and cost-beneficial selection and implementation of countermeasures to address road, vehicle and human factors attributable to road injury and death (Torpey et al, 1991). While this approach was achieving reductions in road fatalities, the reduction line on the graph was flattening in raw numbers. Around this time, Australian researchers began to highlight systemic risks in the road traffic system and in vehicles, calling for more attention to address these system problems (Grzebieta and Rechnitzer, 2001, 2002; Rechnitzer and Grzebieta, 1999). And in 2004 the Australian Transport Council (of Ministers) adopted the Safe System principle to form the basis of Australian road safety strategies (Australian Transport Council, 2004).

Then in 2010, the General Assembly unanimously resolved to declare 2011-2020 a Decade of Action for Road Safety (United Nations, 2010). An agreed Global Plan for the Decade was underpinned by the Safe System principle. However, even in 2016 – more than half way through the Decade that sought to reduce by half the world's road fatalities, they are not declining at all.

A system-focused analysis

There is a growing concern that the safe system principles that are meant to underpin the Global Plan for the Decade of Action for Road Safety are not being applied in countries that are UN signatories to this global commitment. Applying safe system principles means that the road traffic system is designed and managed such that crashes are survivable. That is, this approach assumes that people will make mistakes in the road environment, and efforts are made to correct for, or ameliorate, the harmful effects of any impacts on the human body that may result from a crash event.

This is done by applying resources to prevent the risks of serious injury crashes, based on an understanding of the possible crash types and likely harm to human road users that can result from these crashes and addressing road, vehicle and human behaviours, as well as emergency response services, to prevent this harm from occurring. While preventing crashes from happening is ideal, the focus of the safe system approach is to eliminate the possibility of kinetic energy forces in a crash to result in an impact on the human body causing serious harm. This approach acknowledges that human beings are fallible. They make mistakes. To the extent that they control motor vehicles, lapses and errors are likely to result in crashes in the foreseeable future. A safe road system will prevent these mistakes becoming fatal or seriously harmful.

A system-focused analysis of how serious injury crashes occur can demonstrate how system failures contribute to human tragedies. Just as root cause analyses are conducted in workplace health and safety, a similar process can be applied to the analyses of road trauma events.

Let's apply a system-focused analysis to an example of a fatal crash that occurred in February, 2016 on a rural road in Australia.

The story in this article is true. One of my friends lost her husband in a car crash that should not have happened. This is the story of what happened returning from a lunch outing for Wendy's birthday. It is a classic illustration of a tragic system failure.

Summary of Wendy's Victim Impact Statement

After the last two fatalities on the road we travelled to return home, had the local road authority built a guardrail and improved the safety of the stretch of road where my husband died, I would be a happily married woman with a beautiful, creative husband six years my junior. I would be working as a planning consultant and author and living in the house we designed, and built, on a rural block in a tropical region of Australia.

I believe that Karl's death resulted directly from the road authority's decision (following the last crash in 2015 that resulted in two fatalities) not to erect a guardrail on the stretch of road that is both windy and dangerous, with inappropriate and dangerous road camber, frequent pooling of water and steep embankments. The memorial cross for that crash is located only eight metres from where our car mounted the kerb and tumbled 30 to 40 metres over the cliff into a shallow tidal creek.

The autopsy report showed that drowning was the sole cause of Karl's death.

Wendy's account of what happened

We'd been out celebrating my birthday and we'd had a stellar day. We had had such a brilliant lunch at Mavis's Kitchen that we reckoned there was no need for dinner. We were in no hurry. We had travelled that stretch of road thousands of times since we bought our rural block in 2001. We knew the road very well.

On the wet road, the car aquaplaned on a bend, crossed the double line, hit the kerb, rolled down a steep bank for thirty out forty metres and landed on its roof in a shallow, tidal creek, facing in the opposite direction. I briefly blacked out and regained consciousness in the water. I found myself upside down. After seconds or minutes that seemed like hours, I located and unfastened my seat belt, as I watched water rising and coming through one open front window. Then it stopped rising, leaving me a small air pocket.

I'm sitting upright in the upside-down car in the creek, on the roof, with water to my chin, air above, and the floor above that. It was quite dark in the car because of the muddy water, even though it was light outside. Karl seemed some distance from me. I've been pushed (probably by the airbag) into the back of the car, facing Karl's back. He's tangled in his seat belt.

I have air on my side (the back) and he has none because the car landed on an angle. He's sitting up, silhouetted in water as dark as chocolate milk. I can barely see his head and cannot reach forward far enough to untangle him. His swimming hands describe small circles around his body. He appears to be unconscious. I reach forward and grasp one circling hand with my left hand. He has had no option but to surrender to the water that fills his space and then his lungs. He does not struggle. I hold his hand as he drowns, hearing a shocking gurgle of water, like a large sink emptying. His head flops to one side.

I'm desperate now. The water is still rising. The doors are stuck in mud. I scream: "Karl! Hold your head up!" Screaming at a dead man.

I take a last look at Karl, now slumped forward, and dive down to reach the passenger side open window. I force my shoulders through it, imagining I will need powerful strokes to reach the surface light. I forget to take a breath, swallow, splutter and cough. Then find myself standing in a metre of water outside the car.

Already people are crowding the narrow roadside above. "He's drowning!" I scream to those above. "Help us! Help us!"

Barefoot, trembling, stones cutting my feet, I observe a surreal tableau of airbags, shopping bags and roadmaps floating slowly through the hatch door, heading downstream. I reach for one and stop. How ridiculous!

Then I turn to see two men – later known as Rob and Bill – scrambling down the slippery, reedy bank. They wrench a huge stone from the creek side and smash the driver's side window. Rob dives in three times before he untangles Karl and hauls his lifeless body from the wreck.

When attempts at CPR fail, a police officer announces, first to others ("There's no pulse"), and then to me ("Madam, I regret to inform you that your husband is deceased").

Safe System?

Australia first developed the "safe system" approach based on the principles underlying Sweden's *Vision Zero* (Johansson, 2009)and the Netherlands' *Sustainable Safety* (Wegman et al, 2005). In 2004, all Australian Transport Ministers adopted safe system principles to underlie their road safety strategies (Australian Transport Council, 2004). This promised to ensure that systemic safeguards would prevent inherently fallible human road users to die as a result of a mistake they make on Australian roads.

In Wendy's story, Karl may have made a mistake. Although he was not exceeding the speed limit, he may have misjudged the condition of the road and driven too fast for that bend. It was not raining at the time of the crash and Karl thought he knew the road well. The speed limit was 80km/h, but the advisory speed on the bend in the road was 45km/h. Police estimated that he was travelling at 50km/h.

"Speed was the *root cause* of the crash," the local road authority claimed. Moreover, despite the police report of the crash they said "the car could not have aquaplaned." This is because, as they pointed out, there was a drain culvert near the crash site. However, when we inspected the site – even months later – the drain was covered in fallen leaves. The Police also observed that the fruit that drops on the road in that sub-tropical area also contributes to the road's slipperiness. The Police advised Wendy that had a guardrail been installed in that section, Karl might well have survived. The report on this crash included statements by Police that mentioned a history of serious crashes on this stretch of road – including those where vehicles landed in the river.

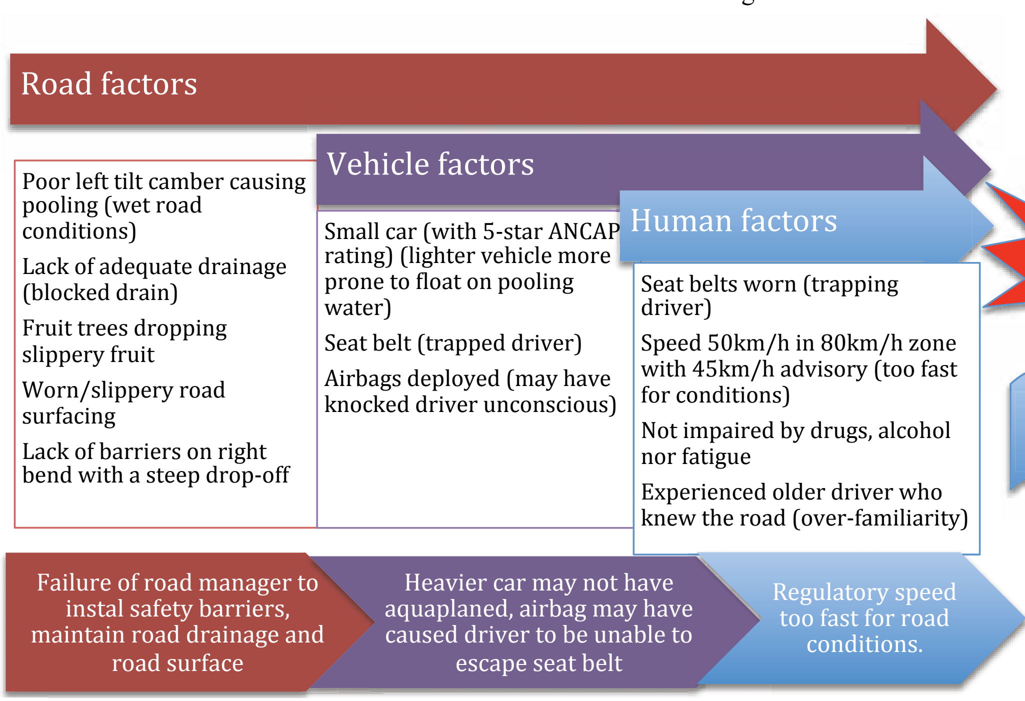

Figure 1. Road, behicle and human factors involved in Karl's fatal crash

However, advising motorists of the danger of that section of road and installing new interactive speed signs, telling drivers how fast they are travelling, was the solution adopted by the local authority following the double fatality crash only one year prior to Wendy and Karl's fatal crash. By September (7 months after this crash) the only action the authority had taken was to prepare applications for Black Spot funding (Black Spot funding is a Federally-funded scheme that road authorities can apply for. In 2016, the State of New South Wales alone had 500 active applications). They expect to be notified of the outcome of these applications in February, 2017 (one year after Karl's death).

Would the crash have been avoided or severity lessened if Karl had been driving slower? If Karl had seen the pooling of water, would he have slowed down, thus reducing the likelihood of the crash? Would Karl have survived if he had not been trapped by his seatbelt?

Wendy and Karl were travelling in a silver 5-star NCAP rated Volkswagon Golf. The airbags were deployed in the crash. If Karl had been superhuman and anticipated all possible hazards on that road and adjusted his driving accordingly, perhaps he could have avoided the fatal event. He clearly was not.

The road system managers did not take this possibility - this *likelihood* - into account. Systemic safeguards were woefully deficient.

Systemic anatomy of Karl's fatal crash

The holes in Reason's (2000) Swiss Cheese lined up to enable a tragedy to unfold for Wendy and Karl. Figure 1 below indicates the system failures of this ent.

While the factors and failures identified here do not represent a comprehensive root cause analysis, it attempts to find some of the systemic inadequacies that contributed to Karl's death. The road was inherently unsafe for human motor vehicle operations. There were no safety barriers on a sharp right hand bend with no shoulder and a steep embankment down to a river. The road surface was slippery from worn pavement, pooling water, and fruit droppings.

Perhaps a heavier car would have held the road better. The car, with a 5-star safety rating, was structurally sound and there was little or no intrusion into the cabin. It is likely that the force of vehicle against the left, then right curbing spun the car backwards and the tumble down the steep embankment overturned the car (so that it landed upside down.) The airbags deployed with a force that prevented the driver sustaining impact injuries, but may have caused him to be unconscious and therefore unable to undo his seat belt.

The driver was travelling well under the speed limit, suggesting that the legal speed was set too high. Misjudgements about speed and road conditions would have contributed to the crash, perhaps due to familiarity of the road resulting in overconfidence.

This systemic analysis is an illustration of how human errors, combined with a lack of safety management, particularly of the road conditions, can result in a fatality.

Part of the systemic problem is a lack of proactive safety management on the part of the road authority. The fact that there had been a number of crashes at this site suggests some negligence on the part of the road managers. If the road were treated the same way as a workplace, the authority would be deemed culpable for the injuries that resulted from these crashes. Instead, the apparent attitude of these managers was that the driver was responsible for safely operating the motor vehicle, regardless of the unsafe road conditions. They even prevented the widow from talking about how this tragedy affected her – citing concerns over occupational health and safety for their staff (who might be upset by the story.)

This local authority said that they intend to make safety improvements – if the Federal or State Governments give them the money to do this. However, the impression given was one of discomfort in having to meet the people affected by the unsafe conditions that they provided, as though this was unfair to them. In fact, Wendy was granted the opportunity to meet with authority's staff only on the condition that she would speak only of the crash itself and not of how it impacted on her life, citing workplace health and safety policies (not to place staff in a situation that may upset them).

Unprotected roadsides on slippery roads with tight curves is antithetical to the "safe system" approach adopted as police by all Australian Transport Ministers in 2004. Roadside and median barriers were tested some years ago at the Crashlab (Transport for NSW) and the wire rope barriers in particular were found to be very effective in preventing serious injury crashes (See http://roadsafety.transport.nsw.gov.au/research/safer-roads/transcripts-road-safety-barriers.html). Yet the local road authority ignored Police suggestions that guardrails should be installed. When we met with this authority on 12 September, 2016, they advised that speed was the root cause of the crash, not aquaplaning as advised by Police attending the crash site. They further said, «[We] have not pursued guardrail at this location in isolation as it does not address these root causes of the crashes at this location. If [we] do not address the factors leading to loss of control on the corner, which it considers to be mainly speed related, [we] will potentially be faced with a maintenance issue from vehicles impacting with the guardrail, and new hazards the guardrail may create."

After Wendy and Karl's crash, the local authority has finally reduced the speed limit from 80km/h to 60km/h. Police estimated that Karl was driving no faster than 60km/h. The advisory speed sign suggests 45km/h around the curve. And while there is little doubt that Karl, being familiar with the road, was driving faster than safe for the prevailing conditions, a 60km/h crash into a guardrail may have caused the authority some "maintenance" issues, but the Police advised that had there been a guardrail Karl probably wouldn't have died.

An examination of authority's budget papers indicates that they spent $13million last year on recreational facilities, instead of erecting a barrier that would have cost around $100,000. They seemed to be of the view that unless they get additional funds from the State and Federal Governments, they do not want to spend money on making their roads survivable.

When we met with the road authority the mention of the safe system approach drew a blank on their faces. It seems that, even in Australia, we have a long way to go to embedding a culture of primacy of safety on the roads. We are still blaming the driver for making human mistakes, without serious recognition of our responsibility to make roads safe. This attitude in and of itself is a systemic failure.

The theme for the 2016 World Day of Remembrance for Road Traffic victims (see http://worlddayofremembrance.org) is "Vital post-crash actions: Medical Care, Investigation, Justice!" In Karl's crash case, investigation and justice were all but absent. The local Police told Wendy that the expert crash investigation unit would not come to investigate a single vehicle crash in a rural location. Therefore the reports of what contributed to the crash were insufficient enough for this road authority to blame the driver for his death. Where is the justice in that?

As long as this complacency and displaced sense of responsibility persists in road-managing agencies, the notion of safe system in reality is a long way off.

How can we break this complacency?

Scientific evidence alone seems insufficient to influence policy makers. There is a wealth of research findings that can guide road designers and managers. Knowledge of what factors are involved in injury crashes is abundant. Knowledge of the solutions and technologies to ameliorate these factors are also abundant. Obviously, there will always be limitations on resources available to create a truly safe road and traffic system. However, the safe system principle demands that crashes should not result in injuries – certainly not in multiple fatalities at the same spot in a road network.

Increasingly, a greater advocacy role is being suggested for road safety researchers. While there are barriers for researchers to assume a policy advocate role, Australian road safety stakeholders by and large want to see road safety researchers become more pro-active in this space (Hinchcliff et al., 2008). The barriers identified include:

- Reluctance to upset or offend research funders;
- Lack of media advocacy skills;
- Lack of time to do unpaid work;
- Reluctance to appear biased; and
- Policy-makers' opposition to researcher media advocacy.

Nonetheless, the majority of stakeholders participating in the consultations undertaken by Hinchcliff et al reported that researcher media advocacy is a significant force within the road safety policy process.

The community voice for road safety in Australia has generally been quiet, relative to the voice in other countries. One notable voice has been Safer Australian Roads and Highways (SARAH), a not-for-profit association established by Sarah Fraser's family and friends, following the crash that killed her. Their mission is to advocate for road safety and to support those affected by road tragedies. In Sarah's case, a truck crashed into her vehicle that was parked in a breakdown lane on a motorway that was too narrow for her car to get completely off the motorway. This crash killed her and the person who came to try to fix her car. The stated beliefs of SARAH (See http://www.sarahgroup.org/background/who-is-sarah/) are:

1. *Each person's life is precious and can therefore never be ethically traded off against traffic mobility*
2. *No person should be placed in harm's way simply because of poor policy, poor planning, poor maintenance or poor procedures;*
3. *Each of us must drive to actively protect other road users, and especially those road users who find themselves vulnerable (ie. those involved in an incident, those who assist and protect, cyclists and pedestrians!)*

These beliefs are entirely consistent with safe system principles. Voices such as SARAH need to have their volume turned up. Were the road safety professionals to work more collaboratively in advocating for change, there could emerge a stronger demand in the community for improved investments in road safety.

Conclusions

Despite all the technical knowledge we have amassed about road safety, Australian road authorities continue to treat safety – at best – as one of a number of competing corporate objectives. Instead of embracing the primacy of road safety, they carry out improvements to road safety only to the extent that budgetary allocations allow. We need to question the values that underpin those budgetary decisions. Until we begin to hear loudly voiced demands for making roads survivable, Australia will continue to fail to meet its *Safe System* objectives.

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Re-invigorating and refining Safe System advocacy

R.F. Soames Job

Global Lead for Road Safety, World Bank & Head, Global Road Safety Facility

Corresponding Author: R.F. Soames Job, World Bank, 1818 H Street NW MC6, Washington DC 20433 USA, sjob@worldbank.org

Key Findings

- Safe System principles and Vision Zero for road safety are delivering successes in many countries.
- However, interpretations of the approach limit advocacy for road safety in two ways:
  - The push for road safety investment and action based on a moral imperative for zero road crash deaths is uncompelling for many critical audiences;
  - The approach is dismissed in many low and middle income countries (and even high income jurisdictions) because the prevention of all road crash deaths is seen as prohibitively expensive and unrealistic.
- Recommendations are made to address these limitations, in order to re-invigorate the adoption of Safe System principles.

Keywords

Safe System, road safety advocacy, Vision Zero, costs.

Introduction

The Safe System approach to road safety is based on asserting the responsibility of the system operators for safety, promoted early in Australia as the accountability of the political system for road safety (Job, Fleming & Brecht, 1989), famously promoted in the USA by Ralph Nader (1965) in relation to cars, and pioneered in Sweden in 1996 (Larsson, Dekker & Tingvall, 2010). It is generally presented as encapsulating the following principles:

1. *People make mistakes:* Humans will continue to make mistakes, and the transport system must accommodate these.
2. *Human physical frailty:* There are known physical limits to the amount of force the human body can withstand before serious injury of death occur.
3. *A forgiving road transport system:* A Safe System ensures that the forces in collisions do not exceed the limits of the human body. (The OECD report 2016 describes this as the need to strengthen all parts of the system so that if one part fails the other parts will still protect the road user: ITF, 2016).
4. *Shared responsibility:* Responsibility for road safety is shared by all system designers, builders, operators and users.
5. *Vision Zero*: The ultimate objective of a Safe System is that no one should die or be seriously injured in road crashes.

The above description of principles has been slightly reworded from a variety of descriptions in many road safety strategies which have adopted safe system guiding principles, including the current New Zealand road safety strategy (NZTA, 2011), the current Australian National Road Safety Strategy (noting that it does include shared responsibility but not as a safe system principle: NTC, 2011), current Australian state strategies (e.g., New South Wales: Transport for NSW, 2012; Western Australia: Government of Western Australia, 2009; South Australia: Government of South Australia, 2011), Ireland's strategy (Road Safety Authority [Ireland], 2013), Poland's strategy (National Road Safety Council [Poland] 2013), and Qatar's strategy (National Traffic Safety Committee [Qatar], 2012). Global guidance documents such as the Organisation for Economic Co-operation and Development (OECD) road safety reports (ITF, 2016; OECD, 2008), the World Bank road safety capacity review guidelines (Bliss & Breen, 2019, 2013), and the United Nations Global Plan for the Decade of Action on Road Safety (UN, 2011) also adopt and advocate for a safe system approach, as do numerous road safety papers (Belin, 2016; Larson et al., 2010; Mooren, Grzebieta, Job & Williamson, 2011).

A Safe System approach has been applied successfully in multiple countries (Mooren et al., 2011; De Roos & Marsh, 2016); Safe System principles and successes have been outlined and promoted (Mooren et al., 2011; Larsson et al., 2010); principles of road design based on a safe system have been provided (Marsh & De Roos, 2016; World Road Association, 2015); the safe system principles are identified as critical for low and middle income countries (LMICs) to adopt, by the World Bank (Bliss & Breen, 2009) and others (Gururaj, 2014); the World Road Association (2015a) noted that its plans include that "Attention shall be paid to the implementation of the "Safe System approach" and its adoption in low and middle income countries"; and the United Nations Global Plan for the Decade of Action on Road Safety advocates for safe systems (UN, 2011). Despite all these promotions, advocacy, successful applications, and guidance from the most credible and influential road safety organisations globally, most road safety activities in LMICs and indeed in many high income countries are not based on Safe System principles. The focus often remains on behaviour change, education, training, and support of victim blaming (Job, 2017). This commentary paper identifies reasons for the non-adoption of safe systems and suggests ways to re-invigorate the adoption of safe systems thinking.

Challenges to advocacy arising from Safety System principles

In addition to the many challenges to road safety advocacy generally, Safe System principles in particular generate two additional challenges. These are considered below.

Challenge 1: The push for road safety investment and interventions is based on a moral imperative for zero road crash deaths which is uncompelling for many critical audiences. The moral imperative of the Safe System approach and vision zero is that no-one should die or be seriously injured in road crashes, and this is commonly the basis of advocacy (OECD, 2016). The concern raised here is not with the ethical imperitive *per se*, but with its use as the key to advocacy in many countries. Many LMICs face multiple major challenges to the health of their citizens. While road crashes kill an estimated 1.25million people per year and over 90% of those deaths occur in LMICs (WHO, 2015), globally road crashes are still fifth among the leading causes of disability adjusted life years (DALYs) behind ischaemic heart disease, lower respiratory infections, cerebrovascular disease, and low back & neck pain (Global Burden of Disease Study Authors, 2015) and in many low incom countries road crash deaths while more much prevalent than in high income countries, have for many years remained at a less prevalent than deaths from diarrheal diseases, and other manageable diseases (Mathers, Boerma & Fat, 2009). Thus, for the governments of many countries a asserted moral imperative to commit the huge resources required to attempt to eliminate road crash deaths and serious injuries is not appropriate to their circumstances or their priorities, and is seen as unaware of the multiple life-threatening problems they must manage. Finally, poverty itself facilitates many of the major health risks (including road crash deaths), and thus road funding is seen (correctly) as a way to improve the country's economy and health. Thus, more kilometres of road allowing effective transport of goods and access to markets, health and other services are seen as a priority. Countering this with a moral imperitive to avoid all deaths and serious injuries is uncompelling. In the author's experience in many countries, the challenge is not that Governments do not care about road safety or their citizens, but that they see crashes as a consequence of improved transport which must be balanced against the benefits of improved economy, improved access, and reductions in the many other problems (including health problems which may be killing more people than road crashes). The ethical imperitive is more complex, and thus presentation of a singular road safety focus can be readily dismissed.

An alternative advocacy approach, which has worked well for the author in many countries is to identify the large economic cost being paid for road crash injuries and deaths, and thus the economic burden which is reduced by addressig road safety. This correctly identifes road safety as a poverty generating issue. A number of specific details are often helpful:

1. It is not uncommon for countries to have made an estimate of costs of crashes from a number of years ago, employing methods now seen as substantially underestimating death and injury costs. It is critical to identify if such a study exists for the target country and point out its limitations.
2. Make a more up-to-date estimate of costs is essential. This can be done as an approximation by employing the iRAP general estimates of the costs of each death and injury based on multiples of GDP per person (70 times GDP for death and 17 time DGP for injury: Dahdah & MacMahon, 2008). It is best to employ estimates of numbers of deaths based on WHO (2015), not official figures if there is a significant discrepency. This will often result in an estimate of crash costs equal to 5 to 6% of GDP per year (see Dahdah & Bose, 2013) not the 1 or 2% commonly estimated (see WHO, 2015 for examples in many LMIC profiles).
3. In addition, Government officials must be persuaded of the credibility of this approach, which is generally quite achievable. Reminding people of the key human and economic impact of deaths around age 18-25 (the age group with the highest risk of road crash death) is helpful.
4. Identify that the costs of crashes are commonly largely born by the Government itself (though emergency services, health care, lost taxes, etc.), and thus the benefits of reduced crash costs will directly reduce Government costs.
5. Identify that deaths and injuries (and thus the costs of crashes) can be systematically reduced by evidence based safety engineering of roads, speed reductions, etc. noting the large benefit:cost ratios (BCRs) achievable. The BCRs show the real value of investment in road safety.
6. Road crashes also risk downward movement to poverty for specific families when the breadwinner is killed or injured to the point of being unable to work.
7. All these discussions must be undertaken with specific detail of the target country being demonstrably considered, not an in principle discussion. This is critical because countries are often focused on what makes them unique rather than the many features they share in common with other countries. Thus, acknowledgement of the country's particular circumstances (which do always exist) and selection of relevant road safety interventions as examples are critical to persuasion.

The above approaches are often effective in persuading governments and government departments in high and middle income countries as well as low income countries.

Challenge 2: The Safe System/Vision Zero approach is dismissed in many low and middle income countries (and even high income jurisdictions) because the objective of a Safe System which prevents all road crash deaths is seen as prohibitively expensive and unrealistic. There are many causes of premature deaths suffered in low income countries (including some more prevalent than road crash deaths) combined with inadequate resources to address them. In these circumstances Vision Zero amounts to the suggestion that these causes of death can be ignored in favour of expending resources solely on road crashes. Nonetheless, Safe System principles provide important guidance for road safety interventions.

Alternative methods of advocacy for a Safe System can be successful, including:

1. The principles of a Safe System are essentially correct for road safety, even if the resources to fully deliver a Safe System are not (yet) available.
2. Even with limited resources, Safe System principles can guide sound investments for better road safty outcomes. Examples of strong successes arising from selected investments in road engineering for safety, rather than a continuing singular focus on education and behaviour change, can be persuasive.
3. The multiple and often unknown behavioural contributors to crashes which must be addressed versus the singularity of an engineering solution for many locations can be compelling as an in-principle argument. For example, multiple serious crashes with cars leaving the road on the outside of a curve on a rural highway may be caused by speeding, fatigue, misjudgement of the curve, drink-driving, drug driving, inattention/distraction, medical episodes, or in rarer cases vehicle problems. To address all of these is a huge underaking, yet all these crashes, regardless of cause, may be addressed by installing an effective safety barrier on the outside of the curve.
4. Description of the case for more focus on managing speeds as a Safe System intervention and the ancillary economic benefits to be capured is also helpful (for details to assist in making the case see Job &

Sakashita, 2016). An appreciation of the role of speeding in crashes in the country will be critical to credibility.

Not even one single high income country has yet committed the resources required to create a fully operational Safe System based road network, though Sweden is the closest and in a number of countries there are some exceptional roads on which a Safe System has been largely provided such as the United Kingdom. Thus, the above suggestions remain relevant to, and can be effective in, high income countries as well as LMICs.

Conclusions

Safe System and Vision Zero principles are being successfully applied and strongly promoted, yet many countries are not embracing them. Two additional advocacy challenges for road safety are created by the Safe System approach, despite its value.

While agreeing with the Vision Zero moral objective of zero deaths on the roads, with many audiences this may not be the most effective basis for advocacy for a Safe System approach. In addition, the objective of zero deaths is seen as currently inappropriate and out of step with the many other life threatening problems LMICs face. Alternatives for promotion of the Safe System approach are available in terms of economic costs, social consequences, and the success of road safety interventions beyond the traditional behaviour change approaches.

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Australasian College of Road Safety Inc.

ACRS, PO Box 198, Mawson ACT 2607 Australia
Tel 02 6290 2509
Fax 02 6290 0914
Email eo@acrs.org.au
Head Office
Pearce Centre, Collett Place, Pearce ACT Australia

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