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The Study of Road Safety on Urban Motorways

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2016 Churchill Fellow

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This report presents the findings of 2016 Churchill Fellowship to study the topic of "Road Safety and Urban Motorways" which involved meetings with a wide range of road safety professionals from nine countries: France, Norway, Sweden, Netherlands, Belgium, Germany, Italy, Greece and Israel.

I am thankful to the Winston Churchill Memorial Trust for providing the opportunity to travel to Europe and meet with many organisations and experts, who willingly gave of their time and held open discussions on a wide array of topics involving many disciplines and perspectives.

I am also grateful to my employer VicRoads, who has supported me in my career and allowed me to undertake this opportunity. VicRoads resourced me to meet with more people whilst travelling overseas and gave me time to follow up the additional material gathered during the Churchill Fellowship to complete this report.

The Churchill Fellowship provided many highlights. Most importantly, the chance to develop relationships with key international specialists, including many who were subsequently engaged as a direct result of my personal visit to their organisation. These relationships will continue to deepen. The most useful ingredients were the openness and integrity which these specialists displayed while answering a wide range of questions and their willingness to share knowledge by providing broader observations on my subject.

The Churchill Fellowship proved to be both a professionally and personally rewarding experience providing the opportunity to see firsthand alternative ways of thinking. I am grateful that the Churchill Fellowship provided the means to step outside of my narrow perspectives to seek answers and insights from other disciplines with different perspectives and experiences to my own.

Any errors of interpretation or documentation are mine alone.

Dissemination of findings

I aim to disseminate my findings through:

- Publication of this report and subsequent refined reports;
- Presentations of relevant findings to the Australian road transport industry, national and international conferences, seminars and workshops;
- Inclusion of important findings in future road design and traffic engineering manuals and practice guidelines;
- Influencing key policy and program decision makers that new approaches are needed to further reduce the road toll;
- The inclusion of findings within National "Managed Motorway" training material.

Presentations delivered during the Churchill Fellowship

The following presentations were made by the author during meetings in all countries visited:

- Managed Motorways Overview (operations and control)
- Insights into Motorway Traffic Capacity and Traffic Theory
- Detailed Crash Analysis of Urban Motorway Serious Injury and Fatality Crashes

1 EXECUTIVE SUMMARY

1.1 Introduction

Casualty crash numbers on urban motorways in Australia are rising, growing by up to 40% in the past decade. The findings of this report suggest crashes will continue to rise without a response that effectively manages the underlying cause for where and when crashes occur. Urban motorways are the "heavy lifters" of road transport as they typically comprise about 7% of the lane kilometres,[1] yet carry up to 40% of the travel[2] in urban areas. Urban motorway crashes comprise around 15% of urban Fatal and Serious Injury (FSI) crashes. Hence this is a significant problem to investigate and findings suggest there are learnings applicable to crashes on the broader road network.

The conditions that lead to most casualty crashes primarily arise from increasing traffic demand which activates certain "Events of Exposure"[3]. These events significantly increase crash risk and, at a faster rate than growth in Annual Average Daily Traffic (AADT), and arise rapidly when motorways carry more than 90,000 vehicles each day[4] or when traffic volumes reach 60-70% of the maximum capacity flow and when average speeds are above 70km/h and well below the speed limit. Importantly the learnings from this study have wider application: wherever these traffic conditions occur for at least some part of the day on rural freeways or divided highways, the crash risk will rise. Events of Exposure often happen within fractions of seconds, and are measurable **providing researchers with a proper definition of relationships between exposure and risk. This re-establishes the connection between the basic concepts of accident research and probability theory.**

For many years road safety programs have primarily focused efforts and resources on treating the more serious crashes only, by reducing their impacts. It has become clear in the course of this study that all motorway crashes are potentially dangerous, thus **the potential for all crashes must be managed**. Most urban motorway crashes (i.e. >75%) are between two or more vehicles and triggered by similar circumstances. Across the distribution of all crashes we cannot reliably predict the outcome of one crash resulting in a fatality and the next resulting in vehicle damage only. These crashes continue to occur despite improvements in infrastructure solutions, vehicle technologies and driver training.

The **potential for all crashes needs to be managed** because the mechanisms involved in crash causation come without warning often giving drivers little or no reaction time. Most motorway crashes occur under a complex regime, comprising similar conditions (i.e. moderate speeds, moderate traffic volumes, high levels of necessary lane changing required to fill up the motorways to capacity), combined with drivers' regulating their individual speeds by minor braking and acceleration movements, numerous blind spots as vehicles travel closely together reducing the amount of empty road space. This is compounded by unpredictable and dangerous "Nucleation Events"[5,6] and separate and independent "Shockwave Events"[7]which usually come by surprise and without warning. Most of these crashes do not involve impacts with traditional road safety infrastructure (i.e. safety barriers.)

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[1] 7% of the pavement area of metropolitan arterial road network

[2] Travel measured in Vehicle Kilometres of Travel (VkT)

[3] "refer (Elvik, Elementary Units of Exposure, 2009)

[4] Which occurs on most motorways in Australian capital cities – some motorways exceed 220,000 veh/day

[5] Nucleus required for both a shockwave emergence or in the absence of shockwave emergence a very high crash risk. A shockwave once activated also rapidly create very high crash risk.

[6] Figure 1 Motorway lane occupancy plot showing nucleation events (circled) - preconditions for crashes

[7] Figure 26 Different backward moving waveforms common in motorway traffic

When crashes occur, differences in outcomes often relate to: the chance availability of a few extra square metres of empty carriageway space, (i.e. stopping or crash avoidance space); the individual driver alertness and driving capability; and the vehicle's unique braking and handling performance in the moments before the collision. Sometimes these events combine favourably, enabling the driver to reduce the contact area between vehicles to be just a few centimetres resulting in "property damage only" crash. However if the contact area is greater than say 20-30 centimetres these crashes may cause major vehicle structural damage transferring forces to the vehicle occupants resulting in serious injuries. **Therefore all motorway crashes are potentially dangerous and efforts must focus on reducing their numbers**. Even a minor crash on an urban motorway has the potential to cause widespread congestion and economic loss, often shutting down major parts of a capital city. During these events, traffic is often diverted onto secondary roads that are statistically four to five times more dangerous for fatality crashes per kilometre travelled,[8] and thus **avoiding all motorway crashes by managing their potential should be seen as important as managing traffic on the road network**.

1.2 There is causal effect between congestion and road safety

Road crashes cost the Australian community about $30B per annum or approximately 2% of Gross Domestic Product (GDP). The impacts of traffic congestion are rising rapidly and the cost to the Australian community is currently about $15B per annum which is expected to increase to around $30B per annum by 2030. A significant proportion of this congestion occurs on urban motorways, which then leads to further impacts on the broader road network. Long-term crash records indicate that total urban motorway crash numbers are rising significantly, and there is a likely causal linkage between congestion and increased crash risk, refer Figure 4.

It seems that motorways have been a "Sleeping Giant" which awakens when daily traffic volumes exceed around 90,000 vehicles a day where certain "Events of Exposure"[9] are activated within the dynamic traffic stream. These events usually trigger either "nucleation events" or "shockwave" events.[10] There is clearly a strong causal relationship between increasing competition for road space and increases in certain common motorway crashes[11]. In particular, Fatal and Serious Injury (FSI) crashes are primarily associated with two separate traffic conditions which are activated when traffic volumes rise. One condition occurs when traffic volumes are moderate[12] and the other condition occurs during the early stages of the onset of the congestion. It appears that the "Sleeping Giant" has awoken and is described in this report as a "Black Swan" event, as now that it has been discovered it can no longer be ignored. The various mechanisms involved in crash causation, discussed throughout the report, must change our understanding of how and when the majority of FSI crashes occur on urban motorways and must change the way we develop effective responses. Discussions during the Churchill Fellowship identified that optimisation of the motorway network can be achieved for both mobility and safety outcomes concurrently. These are complementary objectives, not either/or – as it is often seen as.

Rising crash numbers are evident in Europe on similar heavily trafficked motorways and divided highways which have similar levels of demand as major Australian capital cities, (i.e. >90,000[13] vehicles/day). The increased traffic demand, place our roads under more operational stress than at any time experienced in the past. When any system is overloaded or stressed it will often fail in

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[8] Greater than 20 times more dangerous for casualty crashes

[9] Refer Section 7 Crash Risk a Function of "Events of Exposure"

[10] Refer Section 9, Understanding Crash Causation from Contemporary Traffic Theory

[11] e.g. "rear end" and "side swipe" crashes

[12] Typically Level of Service (LOS) C less than 16 vehicles/km per lane

[13] Many Australian urban motorways have freeway sections with >220,000veh/day on peak weekdays

ways not previously envisioned (i.e. the “Black Swan”).

1.3 Motorway’s are evolving - so too is the road safety problem

This journey of understanding motorway safety has been complicated, having been masked by several other factors as the way we use the roads and road transport evolves. For example, there are major changes to:

- mode share,
- trip purpose,
- increasing vehicle sizes and vehicles mix,
- changing travel patterns[14] with an increasing number of shorter trips as motorways progressively take on the role of arterial roads in urban cities,
- Transference of travel from arterial roads to motorways.

Over the past decade arterial roads have progressively become congested and have transferred much of the additional travel growth onto urban motorway networks whose daily traffic volumes have doubled in the past 15-20 years,[15] whilst daily volumes on arterial roads have remained by comparison relatively static.[16]

This problem was highlighted by SWOV, Netherlands (SWOV, 2007), who concluded that motorways are the safest roads: typically up to 4-5 times safer for fatality crashes and more than 20 times safer[17] for casualty crashes than arterial roads. However in the absence of this transference, crash rates on arterials roads would have been much higher than they currently are. This one significant factor can explain much of the reduction in road crashes in urban areas over the past decade. The concern now is motorways are now becoming progressively more dangerous particularly at the times of the day when the transference is greatest (i.e. typically during extended peak periods – 3 to 4 hrs a day) that are typically experienced in larger Australian capital cities. Thus SWOV in 2007 expressed ***“concern as to what would happen to crash rates when the motorways become saturated and traffic growth spreads back to arterial roads”.***

1.4 It's time to stop, think and evaluate

The road toll is no longer significantly falling across much of the western world when compared to the long-term downward trend of recent decades. There is a high economic and personal cost to the community of increasing numbers of FSI crashes. It is therefore important for Australia to stop, think and evaluate the subject of road safety. As quoted by Peter Van Viet a key leader in Sustainable Safety in the Netherlands:

> ***“Good explanations for the increase in serious crashes and fatalities are still missing”***.

Such a statement is insightful and honest, as it acknowledges a plateauing of road toll reductions. Road safety programs over the past decade, such as those developed in the Netherlands (Sustainable Safety), Australia’s (Towards Zero), and Sweden’s (Vision Zero), have significant challenges in meeting ambitious road safety targets.[18] This is shown in (Figure 41 Evidence of International road safety plateauing) which summarises international road safety outcomes.

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[14] For example origin-destination patterns

[15] Now up to 40% of urban travel measured by Vehicle kilometres of Travel (VkT

[16] refer Figure 62 Total travel on Melbourne's urban freeway and arterial road network

[17] This relates to fatality crashes only they are over 20 times safer for the casualty crash rate per 100MVkT

[18] Somewhat ambitious target of 30% reduction in crashes over the decade

Fundamental changes in context can explain some of the reasons why road safety programs need realignment..

1.4.1 The road safety problem is getting much tougher to solve

The road safety problem is getting much tougher to solve and making things more complicated for road safety is that "Events of Exposure" are not directly related to annual traffic growth (i.e. AADT), but within the dynamic traffic flow itself, where drivers compete for road space. This is occurring for increasingly longer periods of the day, when competition for every available square metre of road space increases driving complexity by reducing the margins for error. When motorways are operating near capacity, it requires precision lane changing manoeuvres into increasingly smaller gaps, and increased potential for blind spots. This significantly increases the crash risk as motorists require higher levels of concentration and mental effort, accelerating side-effects like driver fatigue, which can also lead to crashes elsewhere in the network

The Road Safety program in Australia has seen remarkable success over the past 30 years, by observing problems, collecting relevant data, classifying crashes and responding to them systematically. For example:

- people were being thrown out of their vehicles and/or killed inside their vehicles when they crashed hence we introduced seat belts;
- some drivers were drunk, thus 05 campaigns and breath testing were introduced;
- the accumulation of crashes at fixed locations or along routes led to "Black Spot" and "Black Lengths" programs developed;
- many were having crashes at intersections, hence many safer intersection (mass treatments) were installed (e.g. traffic signals, roundabouts and stagger T intersections);
- younger drivers were crashing and hence improved education and more experience were required by younger drivers before they become licensed.

What became clear from discussions held during the Churchill Fellowship is that the mix of crash types and crash locations are changing and, while the majority of crashes in the past could be classified systematically and treated at a known location, along a route or through a targeted campaign, this may no longer be the case. The historical systematic approach assisted Australia to drastically reduce the road toll despite rapidly increasing growth in travel. This approach served Australia well and was effective in reducing the road toll, particularly when combined with the contribution other industries have made reducing the road toll, refer Appendix B, (An alternative perspective on the road safety narrative).[19]

However, when context changes (i.e. the "Black Swan",[20] it usually requires going back to the drawing board and reconsidering all the assumptions and strategies that have got us this far. Revision of some strategies, a remix of emphasis in others, or new responses to a newly emerging problem is likely to be required to address the emerging road safety problems in Australia. **Without such "evidence-based decision making" combined with critical thinking, road safety programs can quickly lose relevance and effectiveness.**

Future solutions will require us to push down into the "hard to gets" crash categories as a higher

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[19] The role played by improvements in medicine, emergency services, vehicle design and telecommunications

[20] Refer Section 5

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proportion of road crashes now seem to be randomly dispersed, having previously addressed a large number of the very dangerous locations over past decades. Treating the remaining crashes to achieve a further reduction in FSI crashes is becoming difficult, and will require fresh approaches and technical responses to understand crash events that are not related to specific locations.

1.4.2 Comprehending rare events

The traditional approach of treating known problems with physical solutions at known locations needs carefully applied revision in the context of motorways. The dynamics of traffic flow on motorways, increases crash risk disproportionally to annual rises in traffic volumes and creates circumstances beyond current human capacity and typical vehicle performance capability. These measureable[21] events can be seen in the majority of motorway crashes,[22] and have the potential to occur anywhere and at any time in the entire road network, not just on urban motorways.

What became clear during the Churchill Fellowship is that road crashes are extremely rare and unique events, and are the results of billions of interactions that can occur anywhere at any time. Where the next road fatality or serious injury occurs statistically is unlikely to occur at a location where there has been a significant crash history particularly in the past 5 years.[23] Austroads report SAG2090 quotes "***crashes in Auckland, New Zealand, where in 2013 79% of the fatalities and serious crashes occurred at sites with no fatal and serious crashes in the past five years, and 64% of crashes occurred at sites with fewer than two injury crashes in the same 5 year period***". Crash events are therefore extremely rare events from billions of "Events of Exposure".

Every year in Australia the almost 18.9 million registered vehicles, travel more than 250 billion kilometres on 900,000 km of the road network resulting in more than 40,000 casualty crashes and around 1300 fatalities. On average one casualty crash occurs every 6,250,000 kilometres travelled, a distance of 16 times to the moon. One fatality crash occurs every 192,000,000 kilometres travelled a distance of 500 times to the moon and a much greater distance than travelling to the Sun. Therefore the perceived fatality risk to motorists is very small, (i.e. 1 in every 192,000,000[24]km travelled) or mathematically a 0.0000000052 chance[25] of occurring in every kilometre travelled. Therefore these events are very rare events, where we do not know with any real certainty where the next crash event will occur, or what the consequences will be. The motorist, the general public and researchers are not good at comprehending and communicating events which are so rare and substantially random. ***"Humans generally aren't great at reasoning objectively about uncertainty or random events as we go about our daily lives",*** (Today) Refer Section1.6, (The problem of narration bias).

1.4.3 All Crashes are unique having unique circumstances

If a single fatality was to occur in an aeroplane or train crash,[26] there would be a thorough independent investigation and enquiry by trained specialists in order to understand all the mechanisms leading up to the crash, including independently interviewing all involved. As all road crashes are unique and have unique circumstances, and we will not be able to understand the problem(s) until we investigate all the contributory factors at the event level.[27] It is no longer

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[21] Crash events are clearly observeable in traffic data collected at the 20 second level and in even more detail in vehicle event data recorded at sub 1 second level

[22] Figure 13 Graphical representation of speed data showing traffic conditions at time of a crash

[23] Refer AustRoads report on road safety for New Zealand fatalities

[24] About one in every 250 life times (50 years) of driving for the average motorist

[25] A 1 in 6,250,000 for a casualty crash being a 0.00000016 chance for every kilometre travelled

[26] Aeroplane and trains are much safer modes of travel yet have more detailed crash investigations

[27] Refer BASt GIDAS Program

considered appropriate to group crashes into simple categories or patterns in order to understand the causes and develop standard solutions, (i.e. have a toolbox of solutions for matching to crash categories). New methods of data collection and intensity of investigation and analysis are urgently required to fully understand the changing nature and changing the context of road crashes in Australia and to arrive at new and improved approaches.

Many important pieces of the puzzle were identified throughout the Churchill Fellowship and are contained in the full report. When time was taken out to reflect on what were the most crucial issues it was possible to see that, whilst most of the issues apply directly to road safety on urban motorways, a number of important issues also have relevance to the wider field of road safety in Australia. The key findings have been summarised in a progressively developing storyline in Section 2 Key Findings.

1.5 Concluding remarks

Numerous technical resources were brought to my attention during the Churchill Fellowship including: where scientific analysis or normal scientific progress is viewed as development by accumulation (of knowledge). However, (Kuhn, 1962) argues "***normal science is interrupted by the discovery of "abnormalities" which leads to new paradigms***." New paradigms are urgently needed in the field of road safety as so-called "Black Swan" events – something extremely rare, unpredictable or unforeseen – are challenging our current scientific methods and strategies.

Albert Einstein stated that: *"**We cannot solve our problems with the same thinking we used when we created them**".* This implies that new thinking and new solutions will only come about by putting in the hard yards of thorough research to understand the problems. As road transport today is quite different to 50 years or even 10 years ago, there is a need for open inquiry to build on previous learnings and try new approaches that can be scientifically measured over an extended trial period.

The Churchill Fellowship has required a process of "Double Listening", listening to the various views expressed and listening to the Australian road transport and road safety context, by observing the present rapidly changing environment. This was necessary in order to distil relevance and meaning from conversations and to provide a perspective for further road safety investigation in Australia. The "Double Listening" process has identified some very different and potentially unique challenges facing the Australia road safety community. I hope that the findings in this report encourage new ways of thinking and new paths of investigation which will lead to alternative avenues of enquiry in this extraordinarily complex field. This report collates learnings from my many interactions and offers many new insights and opportunities for us to think critically and think laterally.

Finally, I leave the reader with the following words by Henry David Thoreau:

"Though I do not believe that a plant will spring up

Where no seed has been, I have great faith in a seed.

Convince me that you have a seed there,

and I am prepared to expect wonders"

Henry David Thoreau

2 KEY FINDINGS

2.1 Take time out to reconsider and to refocus

There was an overwhelming concern from researchers that the significant benefits gain from historical road safety programs had appeared to plateaued, with Fatal and Serious Injury (FSI) numbers rising, ending a 30 year trend of significant advancement. There was a widespread acknowledgement that current programs may not achieve targets[28] agreed as part of the World Health Organisation's "Decade of Action" program. **If current trends continue, gains made earlier in the decade may be eroded, creating a sense of urgency to respond.**

In several countries there was strong pressure to quickly change course in an attempt to improve strategies. This was seen as a double edged sword: a positive motivation for action but without sufficient time provided to stop, think and collect the empirical evidence on what the mechanism of emerging problems are. As stated in Section 1 above, there is much speculation about the causes of the problems – such as driver distraction by mobile phones and not enough police enforcement[29] – which are not always supported by solid empirical evidence. Evidence was emerging however that something more fundamental was happening that has changed the nature of crashes which is showing up in the crash records across many countries. There was clearly a mood to stop and take time out to critically think before rushing ahead with new road safety programs. It was in this context that the topic of "The Study of Road Safety on Urban Motorway" was approached.

> **"You don't see something until you have**
>
> **the right metaphor to let you perceive it"**
>
> Thomas Kuhn

2.2 Understanding different contexts and changing contexts

Different countries are grappling with quite different road safety problems that are very different to the Australian context. For instance crash problems in the Netherlands were highly skewed towards a cycling and an aging population. It was clearly stated in one meeting that:

> ***"Road Safety programs and solutions developed in Europe***
> ***cannot be directly translated to Australia as the transport context is quite different.***
> ***However, any principles and learnings from the research in Europe***
> ***may be able to be adapted and applied somewhere in the Australian context."***

It is evident that the nature of transportation has changed rapidly over the past decade and that the change is complicated as road transport is simultaneously maturing, evolving and operating under more stress than at any time in history. Many crash types involve different modes, occur in different proportions, at different times of the day, and are more dispersed than ever before.

Road transportation has changed in many ways over the past two decades, including: increased vehicle numbers, variations in vehicle size and mass, changing mode share, (e.g. increasing walking and cycling), changing trip purposes, reallocated road space, and an increasingly aging society. **When systems are placed under additional stress and/or new stress as we use these assets differently, it should not be surprising if they begin to fail in ways not previously anticipated. Similarly, solutions may come from new areas not previously envisioned.**

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[28] targeting a 30% reduction in Australia

[29] Crashes occurring where there is little mobile phone coverage

2.3 Crash risk increases when road assets are stressed

Economists correctly observe there is spare road capacity to further exploit, however, this spare capacity (i.e. "**sweating the asset**") often comes at a cost. It places road networks under more pressure for longer periods of time as road users compete for a scarce resource. This accelerates deterioration of road assets ("**stresses the asset**") requiring more maintenance[30]. Drivers compete for road space by traveling closer together, in larger vehicles, with heavier loads for longer periods of the day elevating crash risk ("Events of Exposure"). These events grow faster than the growth in traffic volumes causing a higher than expected crash risk. Once motorways reach about 90,000 veh/day, there seems to be a tipping point for a non-linear rise in the number of casualty crashes.

Traffic theory pioneers (e.g. Greenshields 1930's, Whitlam & Whitehall 1950's, and Myer & Treiterer 1970's), discovered that traffic flow does not behave in linear or predictable ways as traffic volumes increase. When traffic volumes rise, traffic flow becomes unstable forming both nucleation and shockwave events and hysteresis occurs as revealed by the fundamental traffic flow relationships. If any road system is loaded with too much excess traffic, it will physically stop (i.e. gridlock) - a lesson learnt back in the 1930's. Instability in the traffic flow rapidly increases complexity for drivers thus we should expect increased crash numbers as traffic demands increase.

2.4 A "Black Swan" event – a new finding can change everything

A "Black Swan" event is a rare event where one single outlier (i.e. "a black bird"), is identified, changing the way we consider the world (Taleb). A "Black Swan" event emerged when we combined the latest science of "contemporary traffic theory" and the evidence that reveals when actual crashes occur on motorways (refer Figure 19: Speed plot showing perturbation and shockwave before a crash occurred). These mechanisms are involved in the majority of urban motorway casualty crashes and can be seen in analysis of high resolution traffic data, when matched to actual crash events.

Potentially anywhere in the road network when certain traffic thresholds occur, the crash risk will rise sharply. Such mechanisms emerge out of stable traffic conditions which rapidly become chaotic within seconds catching most drivers unaware. The rapid change in traffic conditions has been described as nucleation events (Kerner, 2017), where a small cluster of vehicles suddenly introduce chaos[31] into the traffic flow triggering a large speed drop. These events are commonly associated with a lane change event (Ahn S, Cassidy M J), and may[32] or may not subsequently trigger a second mechanism being a fixed or moving bottleneck in the form of moving waves (i.e. shockwaves (Martin Treiber, 2013)).

Police crash reports confirm vehicles are primarily crashing into other vehicles, (e.g. >75% of crashes), rather than crashing into safety infrastructure (i.e. barriers). A finding from a recent study of many Victorian police records of urban motorway FSI crashes states ***"that road infrastructure was not mentioned once as being a casual factor in any of the descriptions of these crashes. Instead,***

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[30] Many of the crash mechanisms discussed in this report could also be exacerbated by poor pavement conditions i.e. reduced friction and increased roughness and thus reduced road maintenance budgets may translate into increased crash risk and the need for higher road safety investment. Many rough road surfaces are often simply paved over with a new surface with road roughness reappearing soon after treatment is completed. The accelerated increase in Australia to purchase larger SUV vehicles may also be in some part motorists recognising that rough bouncy Australian rural roads are now being considered as being too hard on normal vehicle tyres and suspensions.

[31] A term regularly used by Professor M. Papageorgiou as to why motorway flows need to be controlled in real time to improve productivity, reliability and safety

[32] Nucleation events will resolve in the absences of high density upstream traffic. Shockwaves require a certain density of traffic before they form and depending on the density you may see up to 5 forms of shockwaves (Martin Treiber, 2013)

mention was made of heavy traffic, congestion and vehicle blind spots." Speeding or excessive speed is rarely mentioned in reporting as a causal factor. The greater majority of **FSI crashes can be shown to be systematic to traffic flow conditions**. Vehicles on urban motorways are not crashing into objects at particularly dangerous geographic locations as was the past situation (e.g. pre 2000) or at established "Black Spot" locations, bringing a new context to understanding many road crashes.

2.5 Higher crash risk in two distinct "traffic states"

The very high crash risk, resulting in a five to six-fold increase in casualty crashes occurs when traffic volumes begin to rise and reach moderate levels[33] with speeds in the range 70-85km/h. Unfortunately this is when "Travel Time" systems would describe these conditions as being "Light".

Under these conditions, additional lane changing is required as drivers seek out spare road space to fill up all lanes to capacity. These conditions involve higher traffic densities which can be variable and a single random event – such as a cluster of two to four vehicles – can jam the motorway suddenly. Motorists that can't stop quickly enough can become involved in an FSI crash. The problem for Australian motorways is now these moderate traffic conditions are occurring for most of the day and FSI crashes are spread right across the entire day (refer Figure 5: Typical hourly profile of casualty crashes on a Melbourne urban motorway).

A second high crash risk "Traffic State" occurs after the motorway has reached capacity and enters in the early stages of congestion, where lane changing[34] seems to increase as motorists appear to jockey for perceived advantage for the faster route as conditions begin to deteriorate within moderate 45-65km/h oscillating average lane speeds. The lower average speed appears to make lane changing easier for motorists to judge.

2.6 Aggressive drivers may cause safer drivers to crash

Contemporary traffic flow theory demonstrates the complexity of urban motorway traffic problems and reveals that often drivers who create trigger events (e.g. nucleations and or shockwaves) are usually not involved in the crash itself. This important finding needs to be further explored as it leads to relatively safe and slower drivers being involved in crashes in the wake of more dangerous and aggressive driver behaviour.

The inappropriate behaviours of a few drivers, who make aggressive braking or lane changes – often described as swooping maneuvers to gain a short term advantage – can trigger a "Shockwave Event" that affects five to 10 vehicles behind in the traffic. These drivers travelling further behind often have no warning and no "reaction time" to avoid a collision. In terms of the Safe System approach[35], these mechanisms provide some challenges as four of the steps in the process occur instantaneously. The driver has: one, no warning; two, no time to make an intervention; three, no time for immediate correction of driving; before four, they prepare for the crash. Designing solutions to reduce these types of events will prove challenging however, from the findings of this report they are now technically achievable.

Behavioural Scientists at The Swedish National Road and Transport Research Institute (VTI) in Sweden indicated it had been a major oversight that road safety campaigns had not targeted certain aggressive driver behaviours, particularly those who regularly tailgate and make severe lane change

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[33] 60-70% of capacity

[34] Lane changes in peak periods have been measured up to 2500 LC/km/ h under peak traffic flows in Australia

[35] Refer Appendix A - Figure 87 Graphical representation of the "Safe System Approach

maneuvers as being unacceptable.

2.7 Wider motorways – equals higher crash risk

A less well known "Event of Exposure" is that crash risk rises more rapidly on heavily trafficked motorways with three or more lanes (Kononov, Bailey, Allery, 2008). Motorways with more lanes require disproportionally more lane change events (Hall M, 2017) increasing the complexity for drivers and disproportionally increasing crash risk. It appears likely that in the future, the design of urban motorways will have an ideal limit on the maximum number of lanes, beyond which the carriageway preferably should be divided into two for both safety and operational efficiency.[36] Further analysis of this topic is now progressing within VicRoads which is an important Churchill Fellowship finding.

2.8 Poor vehicle handling performance elevates crash risk

The vehicle itself is probably the most critical component of the safe system approach and one of the most critical elements when considering urban motorway crashes, particularly as some unstable vehicles are over represented in urban motorway crashes. When considering "Exposure as Events", an increasing number of potentially unstable vehicles are now driving on Australia's urban motorways. Some vehicle types feature highly in casualty crashes as they have less ability to brake and maneuver in an emergency braking situations caused by a "Nucleation Event". This is evidenced by heavy vehicles, larger 4WD's, utilities and motorcycles represented in 45% of FSI crashes.

It seems that certain common Australian vehicles have relatively poor emergency braking and maneuvering performance as evidenced by "Moose Tests"[37] conducted in Sweden. If we are to focus on crash avoidance we must consider whether Australia should only allow those vehicles which can perform safely when driven on the road system for the likely traffic conditions which are expected to present regularly. In addition to ANCAP crash test star rating system, we need to include vehicle braking and handling performance tests and ratings that meet certain safety standards which need to be higher than current standards and tests. Consumers need to know the performance of vehicles they are purchasing. A star rating on braking and handling performance may be required in Australia sooner than later based on test results from Sweden's Tekniken Varld.

2.9 Can the "Safe System Approach" be improved

There are many thousands of extreme speeding events recorded on our road network each day (refer Figure 49 showing one month of speeding events >110km/h and with a single event recording speeds of 264km/h on a urban motorway in the middle of the eastern suburbs in Melbourne). Many discussions were held as to why we continue to talk about a "Safe System"[38] and the role excess speed plays in crashes, yet we continue to sell fast vehicles when maximum speeds of vehicles could be limited.[39,40] Allowing vehicles capable of travelling on our road network at very high speeds is an apparent conflict with our road safety acts and regulations which declare maximum safe speed limits of 110-130 km/h in Australian states and territories. Our vehicles are only crash tested at maximum

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[36] Refer Figure 16 Indicative lane change ratios to service a single point on a motorway, Figure 61: Corridor Maximum Sustainable Flow Rates under various lane configurations and Figure 82 Relationship between lane numbers, AADT and Crashes (Accidents/Mile/Year)which reveal that may be beyond 3 or 4 lanes the complexity increases to the point where human error and thus crash risk may increase sharply

[37] Refer Figure 50 Moose Test to avoid a suddenly appearing obstacle standardized in ISO 3888-2

[38] Refer Appendix A

[39] i.e. 140km/h could be the discussion starter

[40] It should be noted that a vehicle's speed is not related to vehicle's power or over taking ability.

speeds of 64km/h[41] yet have the capability to travel up to three times this limit. Such logic would hardly pass the Australian "Pub Test". In light of Australia's crash problem, it is time to debate this issue. (**It should be noted that reducing the maximum speed of vehicles does not affect their power levels, safety or their ability to overtake other vehicles, as modern systems can allow for short bursts of higher speed whilst restricting high speeds being sustained.)**

Discussions with world leading experts centered on why we continue to allow consumers to buy fast vehicles, knowing that some will be driven by immature drivers and others are involved in criminal activity creating the unnecessary need for high speed police chases. When you analyse Figure 50 Excessive speed on urban motorways away from fixed point speed camera locations, the war on managing excessive speed seems to be a 'no go' area.

Discussions highlighted that motor vehicles have become a symbolic expression of our society's freedoms. Therefore, limiting the speed of vehicles to a realistic level affects personal freedoms. The question then arose, what speed are our collective personal freedoms violated, 250km/h, 200km/h or 150km/h? Do we continue to allow our personal safety to be taken away by the hands of others? The rising road toll particularly on rural roads and evidence of excessively high speeds may bring a much needed focus on this topic, as without a change of direction the public road network is not as safe for all of us as it could be.

While it is acknowledged that it is a politically difficult debate, and this issue will be the will be hard to introduce politically, this issue is the "Seat Belt" issue of 1970 - now 47 years ago, a game changer where Australia could again lead by letting the community know high speed is not necessary for our shared freedoms. It is now time to have the tough discussions with the community. Further details of what has already been done internationally on this topic are included in the report, particularly in Europe and Japan.

2.10 To err is human, to blame it on someone else is more human

It has been well established that "human error" is the main cause, (i.e. 95% involvement in road crashes). However, road crashes are extremely rare events when considering the large numbers of "Events of Exposure" that occur on our roads. Each day of the year Australians drive approximately 700 million kilometres or a distance of about five times to the sun or 260 billion kilometres a year. By comparison, crash rates are low. Most driver errors are corrected by the driver themselves, or other nearby drivers brake and steer to avoid crashing. Larger errors are corrected by the road environment by offering a place for the vehicle to either safely recover or for impact forces to be managed.

Behavioural studies from other industries many decades ago showed that human errors increase with increasing complexity of task, particularly when people are presented suddenly with complex problems that they are unfamiliar with. This is the case in most urban motorway FSI crashes as there is usually no warning and little or no time to react. We have often been keen to blame drivers for making mistakes rather than understanding the elemental mechanisms involved in complex systems that the community has created for these drivers. Understanding the mechanisms involved will lead us to improvements in: driver education; how to design, operate and manage our roads; and the development of vehicle safety systems that avoid or mitigate crashes.

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[41] ANCAP crash test speeds represent the higher end of real-world crash speeds. For example, the frontal offset crash test is conducted at 64km/h. From real-world (US) data, more than half of all fatalities to seat-belt-wearing drivers in frontal crashes occur at impact speeds under 55km/h.

People generally are poor at judging increased crash risk,[42] as situations change when they are driving. Unless road safety risk is somehow imbedded into the long term memory of drivers so it becomes instinctive, it will not be easy to reduce the current crash risk. We must acknowledge the complexities of driving on motorways and other heavily trafficked roads and develop solutions that support drivers. This is what future road safety measures and systems must strive for as we have created the roads and the complex conditions that are now arising. Since we are now demanding that our road space is used in more complex ways, we have new problems to solve.

2.11 Prevention is better than cure – "all crashes must be avoided"

Given the complex mechanisms involved in heavily trafficked urban motorway crashes and the very similar circumstances[43] most motorway crashes occur under, we must focus effort on avoiding crashes" altogether. On urban motorways there are many similar crashes, (i.e. "rear end"), occurring under similar traffic conditions with similar initial speeds and collision forces with greatly differing outcomes. For example, one crash ends in a fatality the next ends in minor panel damage and the difference might be small as a 10 to 30 centimetre difference in the impact zone with the other vehicle or a few square metres of empty road space the vehicle can maneuver into. **Since we cannot scientifically discriminate or speculate on the crash outcomes when vehicles crash under similar circumstances, future road strategies must target eliminating all crashes.** This would be a change in focus for road safety research from "black spots" and route treatments to providing system wide treatments that travel with the vehicle or which intervene and use smart Intelligent Transport Systems (ITS) tools in the roadside.

2.12 A complex problem requires complex solutions

Solving all the complexities associated with a vast array of factors requires multi-disciplinary approaches that consider crash causation. A much broader total system approach where the medical profession, vehicle designers, roads safety practitioners, road designers, traffic engineers, behavioural scientists and process control specialists understand the mechanisms associated with each individual crash, can collaborate to develop broad network wide solutions to reduce the number of crashes.

Further reductions in the road toll will come by understanding that problems occur far more randomly across the road network. In the future, safety may need to travel with the vehicle providing the driver with another set of eyes and another set of hands and the onboard systems and tools to avoid crashes. Many vehicles on the network today include some of these tools.

Once the problem is understood it is possible to develop solutions, as most FSI crashes on urban motorways are caused by complexities associated with the dynamic traffic condition prevailing at the time of the crash. Some solutions are likely come from new road design standards relating to the reducing crash risk as more motorway lanes are added, (e.g. a maximum of 3 to 4 lane carriageways) might be the optimum for both safety and traffic efficiency, beyond which we see a marked deterioration in operational and safety performance. Where there is a desire to add additional lanes to a motorway beyond 4 lanes we may need to consider dividing carriageways into multiple (barrier separated) carriageways.

We can no longer turn a blind eye to vehicles performance standards which vary so greatly, with

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[42] (Elvik, Speed and Road Accidents - An evaluation of the Power Model)
[43] Pre-conditions in the moments before the crash occurs

some vehicles performing very poorly in emergency steering and braking situations. We need to develop new Australian ADR standards in this field that need to be more stringent than current standards which allow for such a vast range of performance variations in our vehicle fleet. New vehicles should be star rated for their ability to brake and ability to perform in an emergency situation e.g. the “Moose Test”, and vehicle which are modified in any way with different brakes, suspension, steering components, wheels or tyres need to be speed restricted or retested to similar standards before they are allowed on the public road network driving at highway speeds.

We must fast track the Driver Assistance Applications that address many of the “Events of Exposure” discussed throughout this report e.g. Lane Keep Assist (LKA), Blind Spot Warning (BSW), Electronic Emergency Braking (EEB), Lane Change Assist (LCA), and Dynamic Cruise Control (DCC) etc. all of which exist today.

If a Smart (i.e. next generation), Dynamic Speed Limits Systems (SDVSL) is developed, a recommendation of this report following discussion with Prof. M. Papageorgiou, is that it is likely that crash risk will be reduced in the high crash risk categories, (refer Table 3 which illustrated the complexity of traffic behaviour and crash risk). The SDVSL will increase traffic productivity by reducing interruptions caused by crashes and by moderating speed to increase the traffic flow through bottleneck areas, (i.e. road sections with a high crash risk) as well as during certain adverse weather conditions, including dew (damp pavements), fog, rain, snow and wind.

2.13 The science that underpins road safety is also evolving

The changing nature of the safety problem is revealing itself in many different and unexpected ways. The science which served us well for many years may no longer be as applicable or effective in reducing further crashes.

A particular “Black Spot” or “Black Length” treatment which was affective pre-1990 may no longer be as effective, due to continuous improvement in vehicles braking, handling and on-board safety equipment.

Road Safety Programs may see further breakthroughs in the simultaneously maturing and evolving transport context when the road safety problem is understood to be “system wide” **where we are less sure where and when the next vehicle crash will occur or what its consequence in terms of injury outcome will be, or where the next pedestrian or cyclist will be hit by a vehicle**. Dealing with an increasingly systemic problem we need to consider safety that travels with the vehicle **wherever and whenever** it goes by providing the driver with another set of eyes and another set of hands with the onboard systems and tools to **avoid many of the preconditions that lead to many crash types.**

Compared to Europe, Australia could involve other parties to a greater degree in reducing the road toll (such as the medical profession, emergency services, telecommunication and vehicle engineering). Given the changing nature of the crash problem, these parties are likely to remain crucial to mitigating the road safety problem and need greater inclusion in policy and strategy development (refer Appendix B:, An alternative perspective on the road safety narrative).

It was articulated during the Churchill Fellowship several times that rising crash numbers is driving new ideas and initiatives, and which often involving pilot projects being fast-tracked before adequate scientific analysis is undertaken.[44] In many cases it was noted that practitioners have

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[44] Typically over the past 5 years

acted without first reading and understanding the lessons already learnt from the historical knowledge bank.

All road safety treatments must be able demonstrate an engineering effect, and/or a behavioural effect that avoids crashes or reduces their impacts through a known mechanism. Discussions with a number of specialists revealed that sometimes good research was not read or correctly comprehended by practitioners, and sometimes ignored as it did not align with the current narratives or strategies. A common statement heard was: **"We must first apply what we already know".**

2.14 Traditional road crash data no longer provides answers to the current problems

A clear message in Europe related to the inadequacy of current data sets. Poor data is often a "catch cry" of researchers. There was a united view stemming from the recent rise in crashes that the traditional crash records are no longer adequate to provide understanding of crash causation. The complexity of the urban motorway crashes and developing solutions requires researchers to look at the problem through a different lens requiring new and more detailed sources of data.

The long-running German **I**n-**D**epth **A**ccident **S**tudy (GIDAS) program at BASt Germany was an excellent example of rich data sets where up to 2000 crashes[45] are studied in minute detail every year, investigating all the way from the moment the crash occurs through the hospital system to recovery, including interviews and detailed analysis of the damaged vehicles. More information is required to understand crash causation, such as the driver's activities in the days and hours before the crash, driver personal circumstances and attitudes towards road safety, to assess the many factors that contributed to the crash including how the vehicle(s) performed in the critical seconds before the crash and how observers understood the crash event. Such a study allows many unique attributes of crashes to be analysed statistically and then used to inform future decision making.

2.15 The behavioural sciences are critical in reducing the road toll further

The Behavioural Sciences are critical to providing an improved understanding of the complexities involved in pre-crash conditions and how they can work with and influence other disciplines to improve road safety outcomes. Behavioural Scientists need to work alongside: traffic engineers (signs and lines, messages and control), road designer (complexity of lane arrangements, geometry, messaging, visibility and assessment of road rules), vehicle designer (reduce distractions, increase visibility and warnings) and in education (awareness of behaviours that increase crash risks) in an effort to improve driver decisions and behaviours by making drivers more aware of their vulnerability particularly when unexpected "Events of Exposure" occur rapidly increasing the likelihood of human error.

Research has shown that humans are poor at assessing increasing levels of risk, both from surveys and observations in real time when they are behind the wheel. Many learnings are detailed in the full report, including how behavioural scientists, with a thorough understanding of issues relevant to road infrastructure and traffic operations, are making significant progress. Major inroads are being made in research, which is now becoming embedded in road design practice, traffic engineering decisions and processes, particularly in universities and road agencies in the Netherlands.

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[45] The GIDAS study is not as selective as other crash studies and hence introduces less bias in their findings as they are selected based on the police and emergency service call outs and not after admittance to hospital etc

3 THE CHURCHILL FELLOWSHIP FOCUS - URBAN MOTORWAY ROAD SAFETY

The study of urban motorway crashes has not been a high priority for road safety studies, particularly in Australia as motorways are deemed to be the safest roads when using the commonly used metric i.e. **crash rates**. However, **casualty crash numbers are rising**, particularly at certain times of the day[46] when traffic demands are moderate, and during periods of congestion (e.g. stop-start conditions). These two clearly separate traffic conditions can sometimes be separated in time by only a few minutes, as motorways can rapidly become congested, or the crash itself can cause the subsequent congestion, hence they are often considered to be caused by the same event.

There has been a gradual deterioration of safety on urban motorways over the past decade. During certain times of the day they can have a higher crash risk than other road types (e.g. arterial roads). Road safety studies must now drill down into the micro levels of the traffic data to understand the dynamics operating in the traffic flow during the moments when the crash occurs, to identify and develop the most suitable road safety response(s).

New understanding of urban motorway crashes is emerging in the international literature, as a result of very detailed analysis of the traffic context at the exact time and location each crash occurs. Analysis is revealing that crash numbers are likely to continue without new understanding of mechanisms that lead up to a crash and developing solutions to prevent them. As most urban motorways have high levels of safe infrastructure, crash prevention needs to focus on operational regimes, including in-vehicle safety systems, smart traffic management systems, and education.

This emerging understanding was part of the motivation for studying this topic as tangible solutions will be possible once pre-crash mechanisms are identified, investigated and understood (refer Figure 1 Motorway lane occupancy plot showing nucleation events (circled) - preconditions for crashes). Refer Figure 2 Higher resolution lane level speed data showing the nucleation events in red. My broad background in motorway design, traffic engineering and ITS operations has allowed me to perceive the complexities involved in identifying the crash problem and hopefully will allow me to assemble many pieces of this puzzle in a coherent way for others to build upon

3.1 The Churchill Fellowship Approach

The increase in both crash rates and crash numbers experienced on Australia urban motorways are also happening in many European countries. Hence my approach to gaining a deeper understanding of this problem is an attempt to gain further knowledge of the complexities involved in road crashes by seeking out global experts from multiple jurisdictions and disciplines from whom new understandings will emerge. It is hoped that these understandings will be able to make a contribution to reducing Australia's road toll on urban motorways and potentially on other heavily trafficked roads with similar operational dynamics and characteristics.

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[46] 3-4 hours each day in both morning and afternoon peak periods

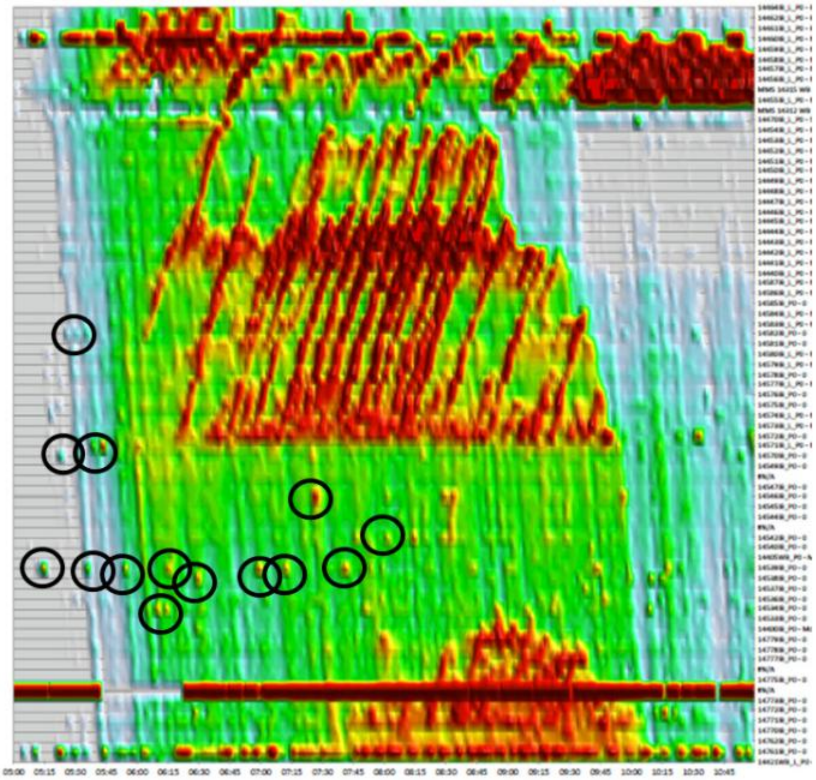

Figure 1 Motorway lane occupancy plot showing nucleation events (circled) – a crash precondition

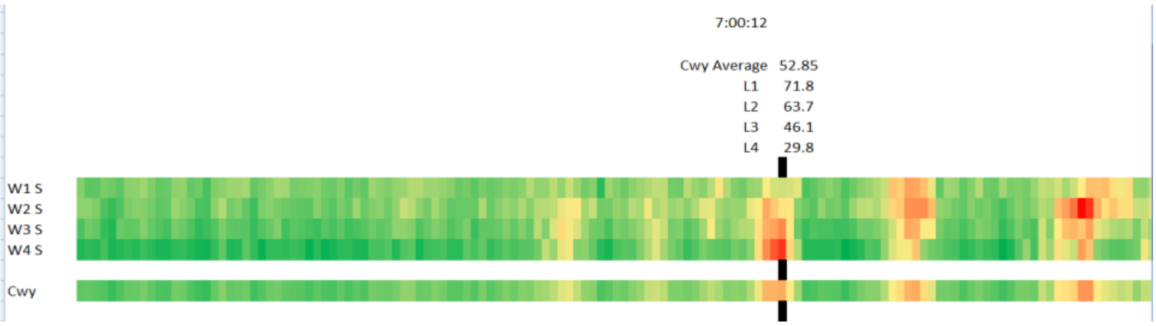

Figure 2 Higher resolution lane level speed data showing the nucleation events in red

My approach involved meeting as many specialists from various disciplines and jurisdictions as possible. I met with behavioural psychologists, traffic physicists, motor vehicle industry experts, road safety analysts, along with researchers in automated vehicles, traffic engineering, road design and traffic operations. At more than 20 meetings, I was able to gain broad perspectives on the perceived critical issues and candid reflections and opinions.

My primary intention is to find out from first principles, how researchers fundamentally perceive and understand the current road safety issues, where crash numbers no longer appear to be declining at the same rate as in the past. During the study I avoided the traditional questions that a traffic engineer might typically ask, but rather challenged the status quo by asking for the thinking and evidence that underpins current initiatives, whilst endevouring to identify the critical mechanisms that trigger many of the crashes seen on urban motorways.

There is clearly national recognition of the importance of road safety although this is a field where there are no easy solutions. Discussion in Australia with road safety professionals indicated the current road safety trend is not meeting public expectations, with a person being killed on Australian roads approximately every 7.5 hours. Some refinements or corrections in current road safety strategy may be necessary. Concern has been raised in Europe and Australia, that if the current trend in fatality crashes continues, many of the anticipated gains i.e. reduction in fatalities during the first half of the "Decade of Action" i.e. 2010 -2020, may be negated (refer Figure 3 Annual fatalities and rate per 100,000 population, 2007 – 2016, where the results could be interpreted as showing only minimal road safety improvement since 2011.)

3.2 Program of Meetings

This section outlines my program of meetings across nine countries in order in which meetings occurred. Many meetings were held with individuals and at some locations meetings were held with a panel of experts in workshops or with larger audiences in seminars.

France

Dr Habib Haj Salem is the Research Director at the French Research Institute for Transport, Development and Network Science and Technology (IFSTTAR) in Paris. Dr Habib Haj Salem has a long association with motorway operations in France as a researcher and is widely published in traffic engineering, control systems to reduce congestion and incidents, and crash prediction methodology. During the visit I also met with staff at the Traffic Management Centre to discuss how safety was being managed on the Paris motorway network.

Norway

Dr Rune Elvik Institute of Transport Economics in Oslo is a political scientist from the University of Oslo. His main areas of research include the effects of road safety measures, research synthesis by means of meta-analysis and cost benefit analysis. His research work on relationships between exposure and risk for road crashes provided many interesting insights to the motorway problem[47].

Mr Kristian Wærsted has been the Chief Engineer of Norwegian Public Roads Administration with many years of experiences in road design, traffic engineering and road pricing. His wisdom and experience on how a country can look at transport problems differently including pricing roads since the 1980's and how appropriate pricing of Public Transport enabled the provision of modern mass transit systems which is possibly one of the key reasons Norway is achieving higher road safety outcomes as it moves many more people by trains which is a safer mode than moving people by roads.[48]

Sweden

Mr Linus Ptojtz and Mr Ruban Borjesson of Teknikens Varld where hundreds of new vehicles are tested annually on behalf of consumers including braking and vehicle handling in emergency stopping situations. The results are made public and published in their monthly magazine and online. This research identified many common Australian vehicles as having some significant handling and maneuvering problems that would make emergency braking and maneuvering on motorways problematic. This work concurred with Australian crash data as these vehicle types

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[47] Unfortunately I was sick for an extended period in Oslo, thus meetings with Rune were held via several phone calls from my hospital bed.

[48] Again due to my hospital stay my planned meetings were canceled, however Kristian and his wife graciously hosted my wife and I on a full day tour of Oslo, having meetings in Kristian's office on the weekend and dinner in the evening for which we were grateful.

appear to be showing up as being over represented in the urban motorway crash statistics.

Meetings and workshops were held with an experienced team of traffic engineering consultants at MOVEA in Stockholm. Meetings included Dr Per Stromgren, Torsten Bergh, and Fredrik Davidsson, and Carlos Moran. This team had undertaken considerable amounts of relevant research on many motorway design and motorway capacity matters including undertaking traffic modeling for the government. Per Stromgren's recent PhD was related to motorway capacity and he had a good knowledge of the motorway over capacity problem (i.e. flow breakdown and congestion) and the consequential increase in safety problems which have emerged in Sweden.

An important visit was made to VTI the Swedish National Road and Transport Research Institute in Linkoping, Sweden, where world leading road safety research is undertaken on all aspects of road safety. At VTI I met with many people including Dr Catharina Arvidson, Dr Sonja Forward and Dr Asha Forsman, researchers in traffic and transport psychology. Experienced simulation expert Dr Jonas Jansson allowed me to experience firsthand simulation of motorway road tunnels, and observing the crash testing facilities with Mr Tommy Pettersson, including his career long research on rear facing child restraints which are now globally recognised as being the safest. Sweden is known for its global leadership on road safety and its focus on clearly targeted research.

The Netherlands

Meetings were held with Mr Berg, Jan Maarten van den, Ministry of Infrastructure and Environment (Motorway Design & Operations Practice) (Rijkswaterstaat) in Utrecht. Utrecht has one of the more impressive Traffic Management Centres with a critical eye on safety and keeping the motorway network flowing. The time spent in Utrecht included workshops, presentations, field trips to observe incident operations with road inspector Mr Hans Kraan and Traffic Management Centre Operations with Mr Gerrit Altena.

An important workshop and discussion session lead by Dr Chantal Merkx, Rijkswaterstaat and her team was held offering much needed insights into the integration of behavioural science within the road design/traffic engineering disciplines starting at the commencements of all new road projects.

Important discussions were held with Mr Henk Heikoop Senior Advisor Traffic & Transport Ministry of Infrastructure and the Environment (Rijkswaterstaat) particularly on the Netherlands motorway design and capacity work which uses similar methodologies to recent Australian research and which can significantly influence road safety outcomes. If capacity values are set too high it results in roads that are designed with less capacity and hence more hours of higher traffic volumes and congestion which are the pre-conditions for crashes.

A meeting was held with Mr Pieter Van Vliet one of the key leaders and developers of the Netherland's Sustainable Safety Program. Peter gave an excellent overview presentation on the current state of play of the program in the Netherlands, openly acknowledging the program's limitations in meeting current targets and identifying urgent corrective changes that are being proposed between 2017 and 2020 to develop a more proactive risk based approach to treatments similar to Sweden. Pieter's wisdom, reflections and honesty were invaluable.

A meeting with Behavioural Psychologist, Dr Marjan Hagenzieker, who has roles at both the Technical University of Delft and the Netherlands Road Safety Research Centre (SWOV). This meeting provided many insights into the importance of psychologists working closely with other transport disciplines particularly in education by arranging teaching and training courses for transport professionals. Marjan indicated no matter from what angle the road safety problem is investigated "human error" is a contributing factor in approximately 95% of road crashes. Unfortunately everyone feels confident and safe negotiating the road network right up to the moment they are involved in a crash. Humans are poor at judging the increased crash risk when certain dangerous situations arise and hence poor at perceiving the consequences of crashes.

Wendy Weijermars of the Ministry of Roads Safety Research, who focuses on driver behaviour, set up a series of meetings on motorway crash analysis that explained the Netherland's sustainable road safety philosophy and approach as well as their current research areas and projects.

A meeting was held with Professor Serge Hoogendoorn and Assistant Professor Victor Knoop from the Technical University of Delft/Amsterdam Institute for Advanced Metropolitan Solutions. Both are specialists in traffic theory, motorway capacity and various motorway operation tools including ramp metering and variable speed limits systems. These monitoring and control tools when used appropriately can have a major bearing on road safety outcomes.

Belgium

Meetings were held with Associate Professor Chris Tampere and Ph.D. student Willem Himpe from the Centre for Industrial Management/Traffic and Infrastructure, Leuven University Belgium. Discussions focused on motorway bottlenecks and how to measure the capacity drop when the motorway speed stalls, as well as many aspects of their road safety research that is clearly showing that crash numbers, are rising and tending to mirror the daily traffic volumes profile which is similar to many other countries including Australia.

Germany

Meetings were held at Institute for Traffic Engineering and Management Ruhr-University Bochum with Prof Justin Geistefeldt, Dr Rainer Wiebusch-Wothge and Professor Wing Wu. Justin and Wing have been heavily involved in the development of the latest version of the German autobahn (motorway) highway capacity design manual (HBS 2015) including the methodology for motorway merging, diverging and weaving analysis.

Rainer has been recently involved in Road Safety studies focusing on children involved in road crashes for which the survey and interview methods bring new understanding to the pre conditions that lead up to these crashes. Interviewing those involved in crashes is now considered a critical source of data and in the future may assist reducing the road toll as crashes now become more of a system wide problem than being associated with fixed 'black spots'.

A series of workshops were organised by Dr Kerstin Lamke Head of Section Highway Design, Traffic Flow, Traffic Control at the German Federal Highway Research Institute (BASt). This included road design specialists, behavioural psychologists and road crash analysis, and meeting with Mr. Claus-Henry Pastor of the Passive Vehicle Safety & Biomechanics Section, Dr Claudia Evers, head of Traffic Psychology and Traffic Education, Dr Markus Schumacher Traffic Psychology, Dr Thomas Jaehrig Highway Design Traffic Flow and Traffic Control, Dr Andreas Schepers Head of Section Accident Analysis, Safety Concepts , Road safety Economics.

Meetings were held with Dr Anja Estel and Dr Jens Ansorge at Strassen the Road Construction Nationwide Operation, Traffic Management Centre in North Rhine-Westphalia. This is one of the most populated states of Germany which includes the cities of Cologne and Dusseldorf. These meetings were in workshop format and involved topics of motorway operations and traffic control.

A meeting was held with traffic physicist Professor Boris Kerner in his home town of Stuttgart. Boris works at the University of Duisburg-Essen and has also had a long association with the automobile industry through Daimler Benz. This meeting allowed exploration of “three phase” traffic theory associated with motorways and how contemporary understanding of traffic theory might be translated into future autonomous vehicles in the future to increase efficiency and safety. If motorway crashes can be predicted in the future it must first be based on the physics of traffic flow and his work is now providing new insights into crash causation.

Meetings were held with physicist Dr Marin Treiber Institute for Transport & Economics, TU Dresden, Chair of Traffic Modelling, Econometrics, and Statistics. Martin has worked closely with Volkswagen for many years and his work with Dr Helbing and others on two phase traffic theory has been the basis of Australia’s understanding of traffic flow on motorways and the disturbances in the flow that result in road crashes. Martin’s traffic modelling work can demonstrate that the vehicles which cause/trigger crashes are usually not the vehicles which are involved in the crash – they trigger events that mean the vehicles behind are more likely to crash.

Italy

Meetings were held with Prof Federico Rupi and Prof Andrea Pompigna at the University of Bologna, Italy. They have carried out investigations into lane flows on motorways and how a country’s road rules on motorways might be influencing capacity outcomes by restricting certain vehicles from using all the lanes when motorway flows are heavy, for example, the keep right rule unless overtaking (our keep left). His work revealed variations from many countries on how the local operational behaviours and rules might influence motorway capacity. Potentially motorways could operate differently under different traffic conditions (i.e. keep left until the traffic volume reaches a higher percentage of capacity) and then they need to use all lanes equally to use the available capacity[49].

Greece

Meetings were held with Prof Markos Papageorgiou and Prof Ioannis Papamichail Dynamic Systems & Simulation Laboratory, Technical University of Crete, Chania, Greece. Discussions focused on control strategies to avoid congestion including the real time integration of dynamic variable speed limit with coordinated ramp metering systems and the future of autonomous vehicles which will still need to have traffic control systems to optimise for safety and efficiency. Modelling work is revealing that it is possible that motorways can be simultaneously optimised for both safety and efficiency.

Israel

Meetings were held with Ayelet Galtzur in Haifa Israel from the Technion-Israel Institute of Technology - Sustainable Mobility and Robust Transportation (T-SMART) Laboratory Faculty of Civil and Environmental Engineering. A visit to Traffic Management Center with Anat G, the head of the center showed that Israel was doing some excellent work in measuring and predicting congestion up to four minutes ahead of real time and then able to intervene and optimise traffic networks to avoid or reduce the impacts of congestion..

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[49] These problems seem more related to specific countries and is less of a problem in the Australian urban context

4 INTRODUCTION TO THE ROAD SAFETY PROBLEM ON URBAN MOTORWAYS

Road crashes are currently costing the Australian community about $30B per annum or approximately 2% of Gross Domestic Product (GDP). Traffic congestion is also currently costing the Australian community about $15-20B per annum increasing to approximately $30B per annum over the next decade for which a significant proportion of this congestion occurs on urban motorways (refer Figure 3 reveals the flattening and potentially rising trend in road deaths in Australia). Whilst the total numbers of casualty crashes are increasing on urban motorway in Australia, this study has primarily focused on the Serious Injury and Fatality (SI&F) crashes which are also increasing significantly on urban motorways as discussed below.

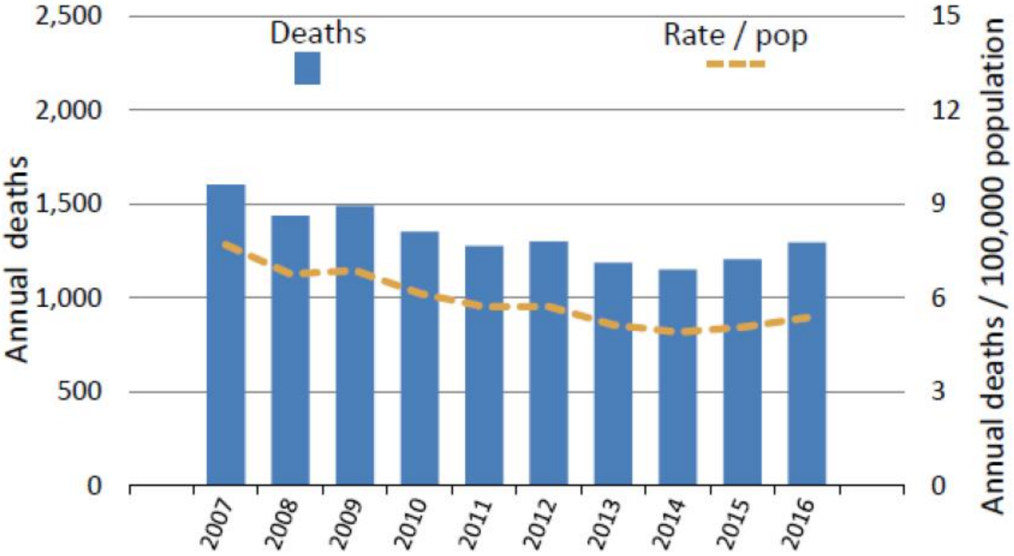

Figure 3 Annual fatalities and rate per 100,000 population, 2007 – 2016

From Figure 3 it is observable that there is some relationship between population rates and fatality rates and in the past, it seems Australia was able to maintain falling fatality rates despite the rising population growth which may no longer be the case. As discussed in this report, this apparent change in trend may be related to evidence that the Australian context for road transport is rapidly changing, particularly how some parts of the road network is now being used and operated.

Some parts of Australia are showing stable or declining road crashes(e.g. metropolitan arterial roads), whilst other areas are showing increases (e.g. urban motorways and rural areas). However as identified from discussions in some European countries it seems to be the heavier trafficked motorways (generally) and divided highways that are showing significant increases in crashes. It could be possible that there may be similarities in the crash causation mechanisms at work on these similar types of roads).

4.1 Crash numbers on urban motorways are rising significantly

A breakdown of the longer term Australian crash trends indicates that rural crash numbers are rising and that metropolitan crashes are relatively stable or declining. While this may be statistically correct, a closer look at the data tells a different story. In Australian capital cities there has been a significant increase, of up to 40% in the number of casualty crashes occurring on urban motorways over the past decade refer Figure 4 Growth in motorway casualty crashes in Melbourne (2006-2015). This has been somewhat hidden by an apparent drop in crashes on urban arterial roads over the same time period. In Melbourne casualty crashes rose 15% on urban motorways in 2016 alone. Both the proportions of common crash types and how these crashes occur has significantly changed over the time, with strong evidence that a new road safety problem is emerging involving new mechanisms of crash causation.

As arterial road traffic demands have become congested over the past 15 years, the additional traffic growth has been taken up by urban motorways network, with a doubling of traffic volumes over the same period.

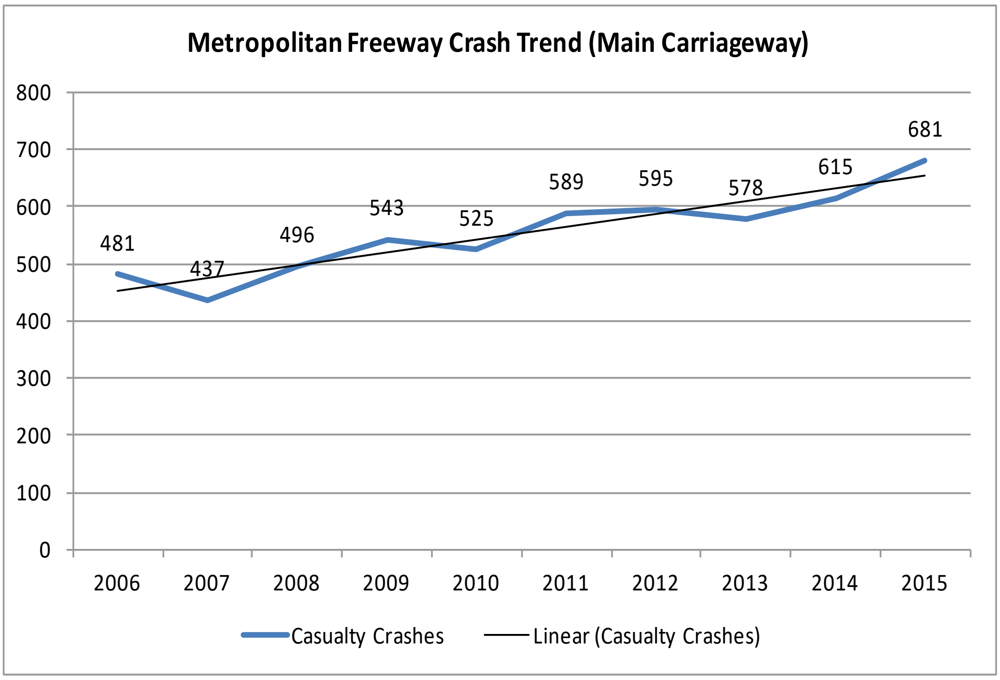

Figure 4 Growth in motorway casualty crashes in Melbourne (2006-2015)

Whilst the measured crash rate[50] on urban motorways is considered low compared to other roads, their very high usage (i.e. now 30-40% of all urban travel),[51] means the total **number of serious crashes occurring on motorways is becoming a significant problem, rising against the urban trend.**

For example, 3058 casualty crashes occurred on Melbourne's motorways over the past five years including 895 serious injury and 37 fatality crashes. This increasing road safety problem is not limited to Australia, as it is occurring in many parts of Europe and the USA. It has also been observed on divided highways with high traffic volumes. Hence the findings of this investigation may have broader application and benefits.

4.2 Motorways are inherently safe - but have the problem of scale

Whilst the measured "crash rate" on urban motorways is very low compared to most other road types, their very high usage (i.e. 40% of all travel in Melbourne occurring on just 7% of the urban network as measured in lane kilometres), refer Figure 71, has resulted in the "total number" of serious crashes rising and which is fast becoming a significant problem. The crash numbers equate to one casualty crash every 15 hours of the year and one FSI crash every other day. These rates are similar in other Australian capital cities with well developed motorway networks with high traffic volumes (i.e. in Sydney, Brisbane and Perth).

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[50] crashes per 100 Million Vehicle Kilometres of Travel
[51] measured in Vehicle Kilometres of travel (VkT)

The high economic cost of FSI crashes on motorways and the consequential additional congestion is induced when a serious crash occurs. As crashes typically occur during the day time hours, this means that there is also a significant road network disruption problem and an economic cost. Refer Figure 5 Typical hourly profile of casualty crashes on a Melbourne urban motorway, highlighting that casualty crash numbers tend to align with peak periods and periods of high traffic demand.

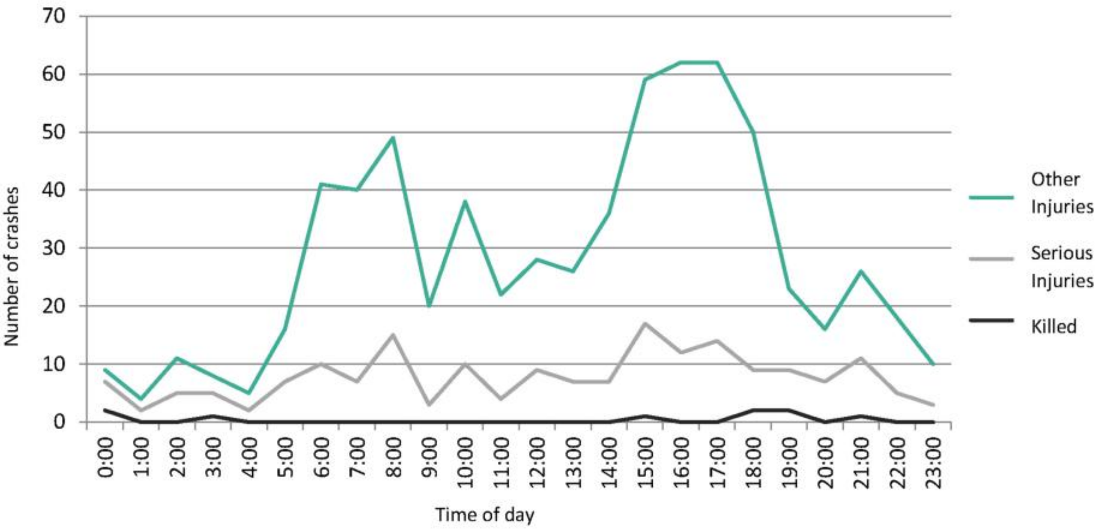

Figure 5 Typical hourly profile of casualty crashes on a Melbourne urban motorway

Similar crash trends occur on motorways elsewhere in the world (e.g. Denver, Colorado USA) (J. Kononov) refer Figure 6 below, revealing that whilst Colorado[52] still has the high crash problem around 2 am, during the night time, as many Australian motorways did many years ago, before we got on top of the speeding and alcohol problem. The pie graphs below clearly shows the mix of crash types and mechanisms involved during the daytime hours are quite different to the night time as observed in Australia, refer (Figure 60 Breakdown of casualty crashes by crash type by hour of day – Monash Freeway).

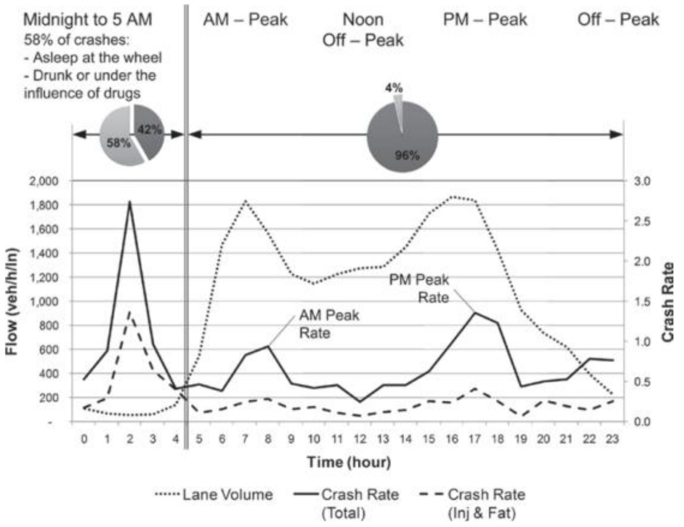

Figure 6 USA Motorway in Colorado showing similar crash trends to Australia

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[52] Australia has successfully addressed much of the excess speed and alcohol problems over recent decades thus reducing the 2am problem

4.2.1 At certain times motorways maybe more dangerous than other roads

Motorways are often seen as a safer alternative than arterial roads, however during certain time periods when the most casualty crashes occur[53] the motorway may be similar or even more dangerous than arterial roads at the same time. In Melbourne, urban motorways statistically have a slightly higher number of persons injured per crash than arterial road crashes which is a significant finding.[54]

So far it is unclear whether crash records in Australia show that crash numbers are increasing on rural motorways in Australia. This might be primarily because the nature of the problem where the complex mechanisms involved in crash risk only are activated on motorways with more than 90,000 vehicles per day (Kononov, Bailey, Allery, 2008) and with three or more[55] traffic lanes. Secondly, it is clear that crash records significantly under report crashes, when compared to hospital records and other databases such as the "written off" vehicles registers,[56][57][58] which provide about twice as many records as the crash records. The true trend may not be evident as many vehicles are "written off", many with airbags activated are not reported unless an injury is evident at the time of the crash[59]. In rural Australia less formal crash recovery processes are in train as the locals often assist their mates with the crash vehicles without the need for police involvement.[60]

One of the often stated claims is that motorway crashes in congested conditions are not so dangerous and hence not so important to study or investigate. While technically correct it is an incomplete picture of the problem, as this is only true when motorways are almost at a standstill (or with speeds less than 30km/h). Also motorways have low crash numbers when their traffic volume is low, i.e. have free flow operating conditions with a Level of Service measure of category A or B. However both these conditions are not when the majority of motorway casualty crashes occur, as crash risk is highest in the moderate to high traffic flow ranges in conditions that typically occur at higher average speeds (i.e. above 70-85km/h, i.e. around LOS C), with a second cluster of crashes occurring when motorways first begin to become congested (as average speeds drop below 65km/h, LOS E).

Unfortunately, most FSI crashes occur when "Travel Time" Systems would indicate traffic conditions are "Light" as travel conditions are still good. The second smaller cluster of FSI crashes occurs in the low to moderately congested state when travel time systems would typically imply "Medium" travel conditions or when average speeds are in the range 40 - 65km/h. Thus these "Travel Times" systems may give motorists a conflicting message as "Light" and "Medium" traffic conditions might imply a low crash risk potentially lowering the driver's concern about the safety risk when it is in fact high.

It was suggested that after entering a motorway from a congested arterial road, drivers may get a sense of relief as their now higher average speed may give them the perception that they no longer need to concentrate as hard as they are moving faster of an apparently safer road type. This could

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[53] typically in peak periods and the high off peak periods with high traffic volumes

[54] Victorian urban motorways 1.3 persons injured per crash versus urban arterial 1.2 persons injured per crash

[55] The crash risk mechanisms increase rapidly as lanes are added to the motorway i.e. double the lanes from 2 to 4 lanes triple the risk

[56] For example UK police records underreport hospital admissions by a factor of almost 4.

[57] It may be in rural areas locals make arrangements with friends after a crash hence there is no police involvement yet their vehicle might be "written off" and they eventually get treated at a hospital.

[58] We have tended to rely on a small sample of police records to understand a very complex problem

[59] This is a matter that should be reconsidered as an airbag activation could be considered grounds for a police report

[60] Most studies of rural motorways are often route based studies, where the crashes on the heavier trafficked sections, in the peri-urban areas, i.e. on the approaches to capital cities, are usually not separated out in crash studies and hence any problem would not be exposed.

not be further from the truth as during the “Light” traffic conditions the motorway is often the most dangerous in terms of crash risk.

4.3 Increasing numbers of motorway crashes should not be a surprise

Growth in travel demand has introduced many complexities in the driving task on urban motorways, such as increasing competition for the available road space. This is compounded by a long-term trend for increasing numbers of larger motor vehicles that are interacting with smaller vehicles, which has resulted in much less physical road space per vehicle. When we drive closer together there are also increased numbers of blind spots. Building wider motorways, for example, increases the mandatory[61] lane changing activity disproportionally to the number of lanes added further increasing complexity for drivers. Reduced road space, requires more intense and precise acceleration and braking events particularly when merging and lane changing requiring greater driver concentration all of which increase the crash risk.

Whilst population growth and its commensurate increase in travel demand should not be an excuse for the increased number of crashes, the increased number of crashes on urban motorways may have been foreseeable to a large degree. This is because it has been known for over 80 years that traffic flow does not behave linearly with respect to increases in traffic demand and traffic conditions can rapidly degrade accelerating crash risk (refer Section 5, A Simple Explanation of the Complexities of Motorway Operation.)

4.3.1 Certain vehicle types are over-represented

Further analysis on Melbourne motorways found that 45% of all FSI crashes involved certain over-represented vehicle classes which include large commercial vehicles, utility vehicles and larger 4WD vehicles and motorcycles. The crash risk is therefore exacerbated by some very common vehicle types of which some have considerably longer braking distances, are less stable handling and this have reduced maneuverability in emergency stopping events which on urban motorways, regularly occur in moderate to high speed traffic (i.e. 70-85km/h conditions).

With this deeper understanding of urban motorway crash causation, as discussed throughout this report, Australia can be optimistic that it can develop solutions to resolve many of them.

4.4 Motorways may be the safest roads built but at times they are chaotic

My tour guide in Italy quite aptly described Italian motorways as being “crazy” as in chaotic, as he avoided them entirely on Fridays when all the heavy vehicles return home for the weekend (as heavy vehicles are generally banned from driving on weekends). The next section provides a simple explanation of the complexities of the motorway traffic flow problem which can be unpredictable. One minute they seem to be genteel, and the next minute they seem to be chaotic. These conditions are explainable and several “Traffic States” which can now be linked to very high crash risk.[62].

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[61] Necessary lane changes to full up the carriageway and to optimise the motorway

[62] Discussed in Section 0 and Section 8

5 AN EXPLANATION OF THE COMPLEXITIES INVOLVED IN MOTORWAY OPERATION

Understanding traffic behaviour, driver behaviour and crash causation mechanisms proved to be a fascinating journey due to the many complexities and paradoxes identified. A simple illustration is needed to help explain the complexity of the motorway problem.

5.1 A simple illustration of traffic conditions and crash risk

Six moods have been used in an escalating spectrum to describe the range of traffic conditions motorists' experience. The moods can swing abruptly on any one journey from Sleepy through to "the Car Park" conditions (see Table 1 below).

1.	**2.**	**3.**	**4.**	**5.**	**6.**
Sleepy	**Genteel**	**Buzzing**	**Anxious**	**Chaotic**	**The Car Park**
"Good Moods"			**"Bad Moods"**		

Table 1 The various moods of the motorway

The "mood swings" of the motorway change from day to day, from hour to hour, and sometimes minute to minute. With each of these mood changes, there is increasing complexity in the driving task, and an increased associated casualty crash risk.

With growing numbers of trips on motorways, more of our travel is occurring in what would be considered as the "bad moods" shown in red above.

Except for the final mood "The Car Park", a condition which involves lots of stress, angst, rage, wasted energy and time, and surprisingly a lower FSI crash risk. However the "The Car Park" condition produces a very high number of "minor injury" and "property damage" crashes which annoyingly impacts and delays other journeys on the network.

The longer the periods of the day or year, where motorists have to drive in these "bad moods" conditions, the more we endure the often unforeseen consequences they bring, which includes a greatly increased casualty crash risk, and a change in the proportions of crash types. For example, there are increased numbers of "rear end" and "side swipe" crashes on Melbourne's urban motorway network, and a lower number of "run off the road" crashes (refer Figure 64 Relative crash rates on Melbourne urban motorway network)

As the traffic volumes rise each day, usually[63] motorways progressively move through these moods typically in order from 1 to 6. This requires increasing concentration by drivers who need to be on high alert. "Anxious" and "Chaotic" moods require high levels of concentration as motorists exploit every last square meter of road space as the road fills up to capacity. In these conditions there is no margin for error, as minor mistakes or traffic disturbances can have significant consequences.

However, what is usual may only represent about 50% of the time. It is not uncommon for the mood to jump from level three, Buzzing, through to Chaotic or The Car Park. Rapid mood swings can catch unsuspecting drivers unaware resulting in crashes.

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[63] not always as motorway can suddenly skip certain moods – jump from mood 3 to 6 in seconds

The same happens in reverse, as motorways begin to improve after the peak period. The mood can suddenly change from The Car Park condition to Buzzing. After evening peak recovers it usually moves from level three, sequentially back to level 1.[64]

5.1 Traffic theory explains the mood swings

Contemporary traffic theory reveals many sequences of moods are possible e.g. 3, 4, 5, 4, 5, 3, 6, 2, 5, 6. This has made it hard for traffic scientists to understand the complexity of crash risks and even harder for drivers. Crashes usually come "out of the blue" giving motorists no obvious cues to pick up on, before the bad moods and the higher crash risk suddenly occur.

The mechanisms that describe each of these moods have been well described in research literature for many decades, but unfortunately they have not translated in to everyday road safety practices.

The same mechanisms that cause the majority of minor 'property damage' crashes also cause casualty crashes, and this has important consequences for future road safety strategies.

These moods swings have been clearly described by traffic physicists for over 80 years and more recently by complex gas particle models in the last 25-30 years. Gas particles show[65] the progression through the different moods[66] which are now visible in high resolution traffic data. The "Three Phase" traffic theory described by Prof B. Kerner visited during the Churchill Fellowship breaks these moods into three categories which has been adapted as shown in Table 2.

1.	**2.**	**3.**	**4.**	**5.**	**6.**
Sleepy	**Genteel**	**Buzzing**	**Anxious**	**Chaotic**	**The Car Park**
Free Flow – Low Flow		**Moderate to High Flow**		**Moderate to Low Flow**	
Stable Asynchronous Phase		**Transitioning[67] Metastable Phase**		**Congested- Synchronous Phase**	

Table 2 The various moods of the motorway adapted from B. Kerner's Three Phase traffic theory

In Table 3 below the three traffic phases[68] have been used to illustrate where the different moods sit in relation to traffic flow theory. It illustrates when the motorway is most productive,[69] when it is safest, and the conditions when the moods can abruptly change from good to bad moods. The second last column describes the relative stability[70] of the traffic flow which may change rapidly between phases. What can be seen is there is more than one range where the crash risk is high. Table 3 also includes indicative "Level of Service" (LOS) categories which relate traffic density to each of these moods. Although the Levels of Service break points are not precise they indicate near where the boundaries lie.

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[64] The Phenomena of Traffic Hysteresis first described by Treiterer and Myer 1974

[65] i.e. not the micro-simulation traffic models generally used today

[66] It is possible when examining high resolution traffic data that each of the 6 moods have a distinct class of driver behaviours

[67] only stable if subject to small disturbances (i.e. "Metastable)"

[68] Terminology has been adapted from B. Kerner's three phase theory – B. Kerner's terminology.

[69] Motorway Productivity measures as product of Speed X Flow

[70] i.e. usual but not guaranteed

Motorway Mood	Traffic Conditions	Productivity/ Indicative Level of Service (LOS)	Crash Risk in relation to FSI crashes	Traffic Stability	Traffic Phase
1.Relaxed	drivers freely choose their own speed and path on the motorway	Low LOS A <7 car/km/ln	Low FSI Low all crashes	Stable	**Free Flow** i.e. low flow
2. Genteel	drivers scoot along occasionally having to adjust speed or change lane	Medium LOS B >7 to <=11 cars/km/ln	Low FSI Low all crashes	Stable	**Free Flow** i.e. low flow
3.Buzzing	drivers need to be highly aware of other vehicles, align speed with others, collaborate and judge their position (blind spots)	Moderate to High LOS C >11 to <=16 cars/km/ln	Very High FSI including 3 or more vehicle crashes High all crashes	Moderately stable[71] but may transition to unstable (5)	**Moderate to High Flow**
4.Anxious	drivers exploit all empty road space competing for advantage (negotiate small gaps and faced with many blind spots)	High to Very High LOS D >16 to <=22 cars/km/ln	Moderate to high FSI crashes[72]	Fragile Likely to suddenly transition to unstable[73]	**Moderate to High Flow**
5.Chaotic	traffic waves are present which surge erratically up and down the motorway, traffic may stop regularly for short or long periods. Driver get excited, increasing their lane changes seeking apparent advantage	Medium LOS E & Low F (moderate with "Managed Motorways" >22 to <=32 cars/km/ln	High FSI High all crashes	Unstable	**Congested Flow** I.e. Moderate flow
6.The Car Park	drivers shuffle between lanes for apparent advantage in slow or stopped traffic	Low Higher LOS F >32 cars/km/ln	Low FSI High property damage	Stable/ Transitions to back "Buzzing"	**Congested Flow** I.e. Low flow or carpark

Table 3 Table illustrating the complexity of traffic behaviour and crash risk

Table 4 Table illustrating the complexity of traffic behaviour and crash risk

The reason for the high crashes under "Buzzing" conditions is that traffic flows, speeds and densities are quite variable and average speeds are moderately high (70-85km/h). Under these conditions there is significant potential for "Nucleation Events" where vehicles can randomly form dense clusters. This is described by B. Kerner see Figure 1 Motorway lane occupancy plot showing nucleation events - preconditions for crashes. These "Nucleation Events" occur in the moderate speed conditions, where drivers can be caught unaware having to brake suddenly.[74][75][76] The "Nucleation Events" are now visible in the 20 second data shown in Figure 2 Higher resolution lane level speed data showing the nucleation events in red on a 4 lane motorway.

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[71] Almost always stable with "Managed Motorways"

[72] Potentially low refer (Figure 21 Relationship btw Lane Occupancy and FSI Crashes - 5min resolution)

[73] Substantially stable with "Managed Motorways"

[74] In Figure 2 a nucleation event occurs when the left lane WS4 suddenly slowed to from 86km/h to 29.8km/h within 80 seconds and the density of the traffic suddenly spikes (doubled). In this 80 second event 160 vehicles move past this point of the motorway.

[75] refer Figure 18 One minute flows typically represent 120-160 vehicles.

[76] Certain vehicles have lower braking and maneuvering capacity which elevates crash risk.

6 THE RAPIDLY CHANGING CONTEXT OF URBAN MOTORWAYS

6.1 The Importance of Urban Motorways to the Australian Economy

This section outlines some of the many changes that are occurring in the Australian society and economy that are influencing how urban motorways are being used. The relatively affluent Australian lifestyle enjoyed in our capital cities is heavily dependent on the abundant supplies of goods and services, for which the motorways play a vital role in delivering.

Growth in traffic on Australian urban motorways is increasing rapidly in capital cities as population increases, and the now largely “services-based” economy amplifies traffic growth by placing more pressure on major urban roads. Tourism, for example, now employs some 200,000 people in Victoria, while strong housing and commercial building growth involves supplying building materials and services for new housing, commercial properties and new public infrastructure including investment in hospitals, universities, railways, seaports, airports and community facilities.

In a growing service-based economy, motorways have moderate to high traffic demands for much of the daytime hours, seven days of the week. This creates the “critical precondition” for most casualty crashes. Competition for road space increases the crash risk, because there are more chances of human error with increasing complexity of the driving task.

Most urban motorways experience heavy or congested traffic conditions every day of the week and the difference in the traffic volumes between the lowest traffic volume day (typically Sunday), and the heaviest weekday is rapidly closing. More people are now transported on the urban motorway on weekends than weekdays, with higher numbers of passengers per vehicle. Fewer public transport services and fewer parking restrictions on weekends exacerbate road trips by creating increasing weekend traffic demand.

6.1.1 The service-based economy

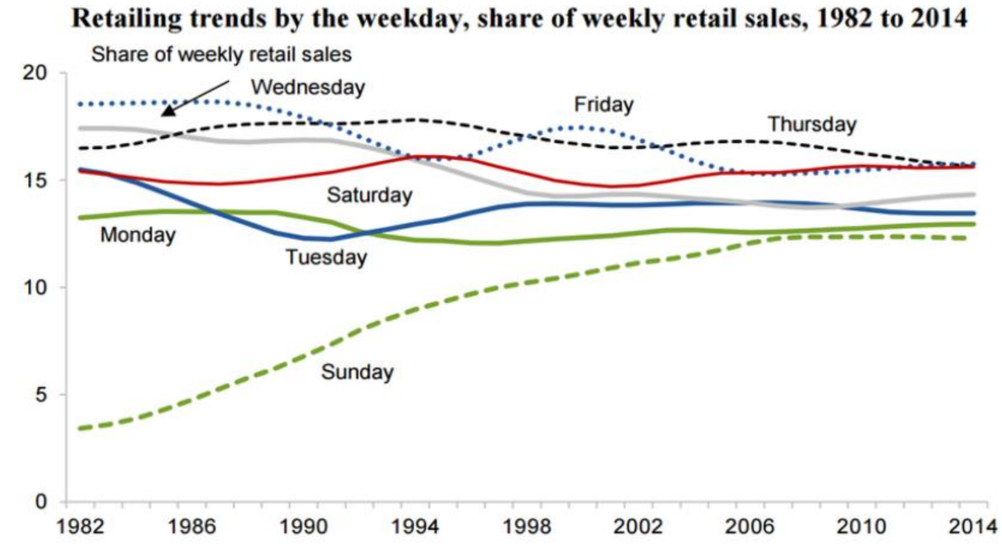
The “service based” economy is now approximately 75% of economic activity in Australian capital cities. This has resulted in the transport task being widely distributed and dispersed (**every locality, every business premise, every dwelling is a potential service point every day of the year across all suburbs)**. Combined with gradual changes in retail trading hours over the past 30 years means that roads are the lifeblood of the city supplying products and services that are being delivered to all parts on the city on a 24/7 basis of which urban motorways are the heavy lifters.

Services are being delivered to people while they are asleep and when people are on the move away from their home or delivered at their workplace e.g. delivering flowers to restaurants or parties via couriers using telecommunications systems, which also require road transport services to provide and maintain them.

Our Australian way of life, including the supply of fresh food, often from interstate, regional areas or more commonly now from overseas, are delivered to our shops, restaurants and homes. Our high standard of living brings high consumption of goods, combined with our numerous recreational pursuits resulting in the excellent livability of our cities which are dependent on efficient and safe transport systems to deliver goods and services. **Often this heavy reliance on transport services is not comprehended by consumers, being taken for granted as quality goods and services become readily available wherever we turn**.

6.2 Changes in the way the road system is used

The following graph, shown in Figure 7 Changes to Australia's retail trading over time by day of week, illustrates the changed shopping habits over the past 35 years. Over time there has been a convergence towards retail activity being similar each day of the week compared to 35 years ago, when Friday was clearly dominant and Sunday trading was almost non-existent. This significant change, combined with the growth in retail sales means that employment and service patterns have greatly changed, and this is being reflected on the roads. The spread of crashes on our roads is now across most of the day and the week.



Note: Based on estimating trading days effects on ABS monthly retail data.

Figure 7 Changes to Australia's retail trading over time by day of week

6.2.1 Changes in freight distribution patterns and delivery of new services

Many services are now often home based, and online shopping services demand fast deliveries "just-for-me", wherever we are. This has significantly changed both the freight task and the vehicles they use, with a combination of very large and smaller service vehicles including motorcycle and bicycle couriers. Another example of the change is that hospital medical services over the past decade, has shifted increasingly towards outpatient care, with hospital now operating in the home services domain. The Royal District Nurses Services (RDNS), as one example, generates some 11,000 [77]visits each day in home visits in Melbourne, placing more pressure on the road system[78].

6.2.2 The motorway are operating under more pressure

Urban motorway routes historically functioned as major routes connecting regional centres to urban centres, and for servicing the longer distance urban trips within the capital city. However they now increasingly perform the role of intra-urban arterial roads as the arterial road network has become oversaturated with traffic with minimal additional road supply over recent decades. The overall proportion of increase in road supply is small when compared with the growth in vehicle kilometres travelled (refer Figure 8 Growth in travel vs. growth in road supply –Victoria).

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[77] Refer RDNS annual reports

[78] This has reduced medical provision costs but also results in a transfer of some cost to the transport sector particularly for road maintenance

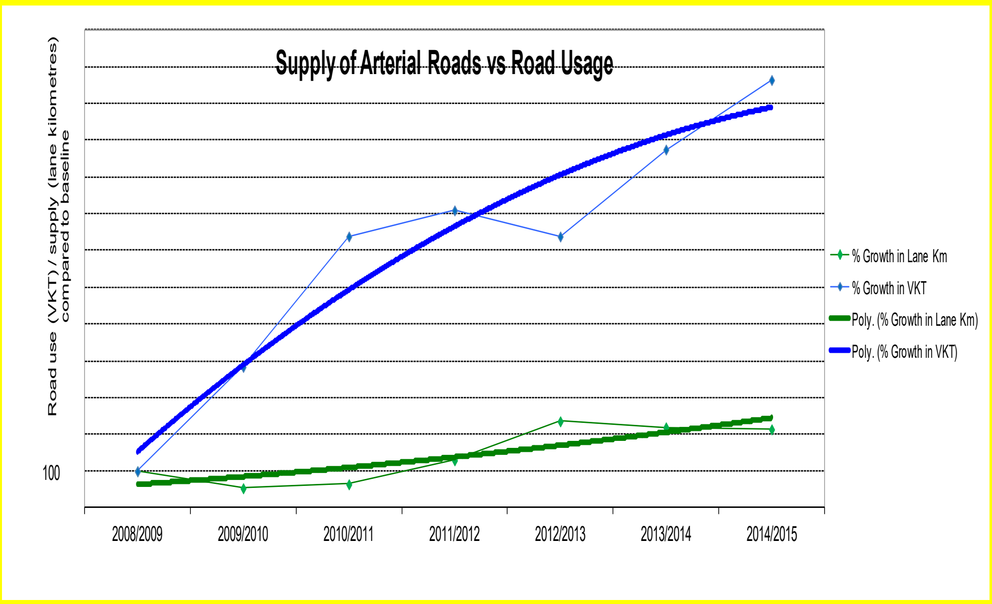

Figure 8 Growth in road travel vs. growth in road supply –Victoria

Australia's increased affluence has ensured that both travel and consumption of goods per-capita has continued to rise, placing more pressure on the road system. The symptom of this is longer peak periods and longer periods of time when roads operate at higher traffic volumes, with longer periods of congestion each year. When systems are under stress they fail in certain ways that may not have been anticipated.

The road supply and demand problem identified above combined with: higher density dwellings, alternative arterial road operational strategies in pursuit of livability outcomes including giving priority to other modes such as bicycles, walking and on road public transport; and on road parking strategies that have remained reasonably static over time, have tended to further reduce the productivity of arterial roads when they are needed most. The urban motorway network has absorbed most of the increased travel demand through transference of trips.

Increases in road crashes are one of the many consequences of a heavily stressed road system. "Sweating the Asset" has consequences. In cities where there is higher economic activity (i.e. Europe and USA, and where there are higher traffic volume levels on motorways with >90,000 (Kononov, Bailey, Allery, 2008) vehicles per day there is likely to be increased road crashes, a phenomena[79] which is occurring on motorways in many of the countries visited as part of the Churchill Fellowship.

6.3 The scale and nature of motorway demands

Urban motorways in Melbourne, represent only a small percentage of the urban arterial road network i.e. typically 7% of lane kilometres. This pavement area is carrying up to 40% of the travel measured in vehicle kilometres of travel. This ratio is similar in all Australian capital cities with the urban motorway share of traffic having typically doubled in the last 15 years. One motorway within urban Melbourne provides between 750,000 and 900,000 vehicle trips every day of the year along its length as well as servicing major freight movements to and from the air and seaports[80]. The

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[79] A phenomena which activates certain "Events of Exposure explained in later Sections of this report

[80] measured by the sum of all entering flows into the motorway each day

enormous scale of the work done by urban motorways and their contribution to Australia's economy and employment cannot be underestimated.

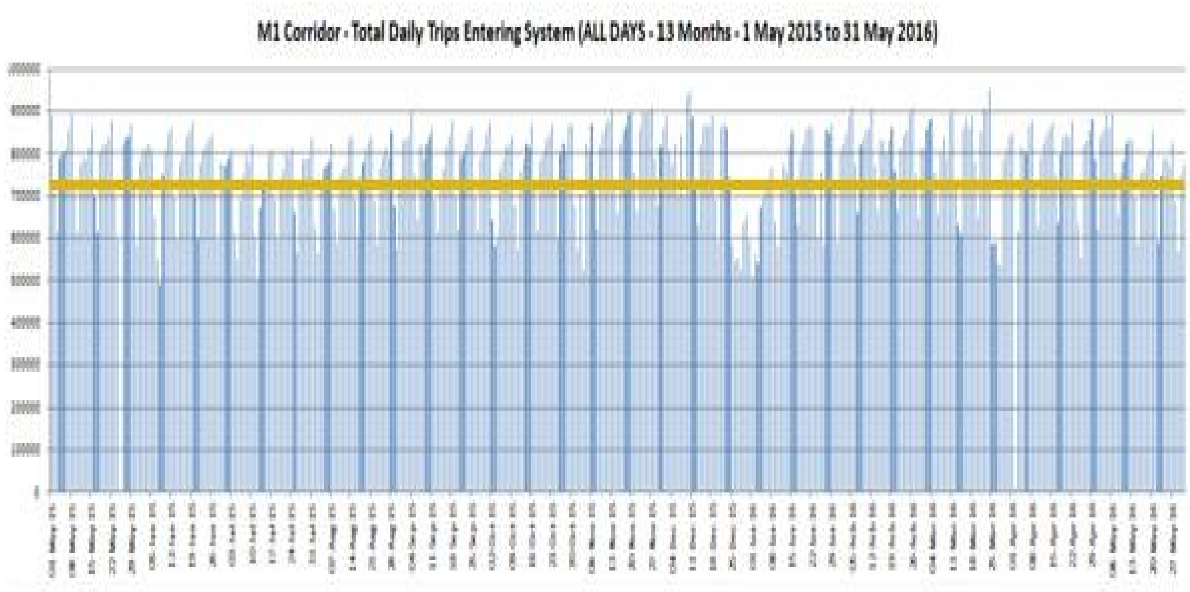

Figure 9 Daily trips measured over 13 months on the M1 Motorway in Melbourne

Every day of the week a single motorway in Melbourne (the M1 motorway) transports more than 1 million people, about twice the number of people[81] that the entire Melbourne metropolitan railway system, with its 16 radial lines, carries on a weekday. [82] One million people moved by road is the equivalent of 1000 trips each day in a six carriage train set[83][84].

What is often harder to comprehend is that only about 20% of the motorway travel on weekdays is commuting, although this may be as high as 50-60% during peak periods. Business and commercial vehicles when traveling on the motorway are usually deemed to be "already at work". Other trips types (e.g. shopping, education, recreation, entertainment and tourism) are also significant in a healthy "service based" economy, which not only produces goods and services, but also consumes them, often during daytime hours of 5am to 8pm (refer Figure 10 Daily profiles of trips on M1 Motorway (15min). The consumption side of the economy is often ignored, but is equally vital part of liveability and a healthy economy for which urban motorways play an important role.

6.3.1 Increasing complexity in the driving task on the urban motorway.

The changing nature of urban motorway use has increased the complexities involved in driving on them. There are hundreds of thousands of different drivers each day interacting, all with different driving behaviours and driver moods, driving different vehicles shapes, sizes and types and all having different origins and destinations. This creates both a logistics and a road safety challenge each day of the year as they all have to enter the motorway and travel along and then depart from the motorway which is shared by all the other 800,000 drivers.

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[81] http://www.metrotrains.com.au/who-we-are/

[83] Melbourne has 210 6 car train sets on it railway systems

[84] http://www.metrotrains.com.au/who-we-are/

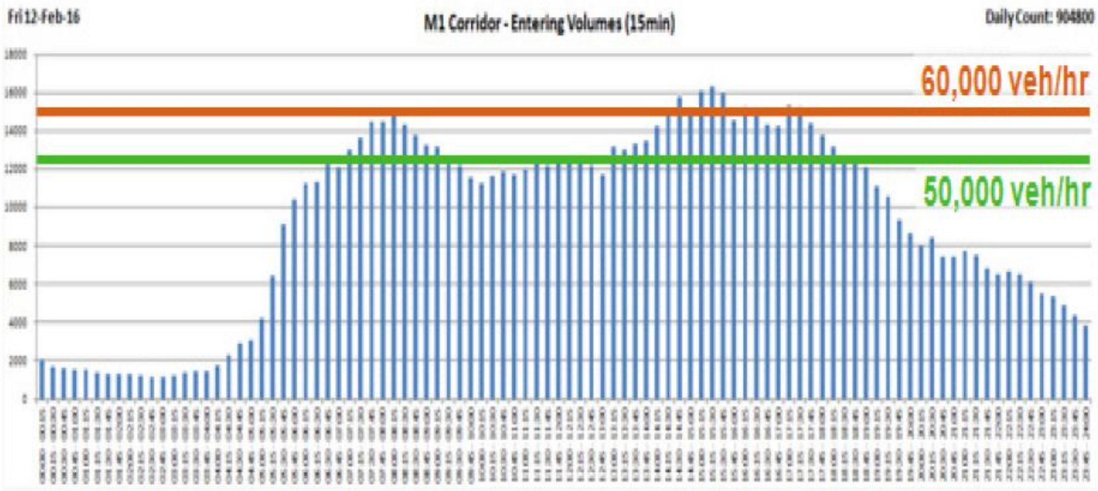

Figure 10 Daily profiles of trips on M1 Motorway (15min)

The motorway has a complex operational regime where vehicles typically operate over the day at speeds of 80-100km/h whilst allowing all vehicles to regulate their individual speeds and driving styles. Complex tasks of merging, diverging and weaving creates 10,000's of necessary lane changes each hour to efficiently load and unload the motorway. The M1 motorway in Melbourne typically has a minimum of 50,000 vehicles each hour of the day entering and 50000 vehicles exiting the motorway from all of its entry and exit ramps between 6:30 am to 7:00pm at night. During peak periods this can increase to over 60,000 veh/h making the traffic loading and unloading activity on urban motorway quite intense, refer Figure 10 Daily profiles of trips on M1 Motorway (15min).

When urban motorways over time are progressively upgraded and widened, there is typically a commensurate adverse impact on road safety as it increases the number of necessary lane changes disproportionately. For example, doubling the lane numbers from two to four lanes results in tripling the lane changes required to fill up the carriageway to capacity[85]. This increases vehicle interactions and crash risk "Events of Exposure". This safety issue is often masked in the initial years following the upgrade – with a honeymoon period of one to two years when more hours of the day drop below the critical LOS C value a key marker of crash risk. However when demands increase such that the same period of LOS C operation is experienced as in the before case, the crash risk will be much higher due to the greater intensity of "Events of Exposure"[86] due to primarily to increased lane change events.

This Section has highlighted that driving on urban motorways has progressively become more complex, as the use of motorways have evolved, as their role has changed, and a significant amount of travel growth has been transferred from arterial roads. Driving on motorways is now a more complex task requiring drivers to be at full concentration, collaborate with other drivers, often through eye contact, regularly adjusting speeds and driving lines to stay within lanes, with the expectation that drivers will make as few errors as possible. However all drivers make mistakes and most of the time they get away with it, as other drivers around them adjust speed and driving lines to avoid collisions. Sometimes however minor mistakes can have serious consequences particularly for other nearby drivers in the traffic stream, as discussed in the next Section.

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[85] refer Figure 16 Indicative lane change ratios to service a single point on a motorway

[86] Refer Section 6 Crash Risk a Function of "Events of Exposure"

7 CRASH RISK A FUNCTION OF "EVENTS OF EXPOSURE"

When traffic volumes are moderate to high, traffic conditions can change rapidly between what is described as "Traffic States" where traffic conditions can change from being good to bad to ugly in a matter of minutes or sometimes within seconds. This rapid change in "Traffic States" occurs on all medium to heavily trafficked roads including rural motorways and highways.

When certain "Traffic States" exist the crash risk immediately becomes very high. As these events often only last for seconds they are not usually recorded in crash reports, however the clues to these events are described clearly in police reports with words like congestion, blind spots or "we did not see the other vehicle".

Traditional crash analysis using Annual Average Daily Traffic (AADT) volumes do not necessarily identify the increasing crash risk associated with "Events of Exposure". These 'close shave' events occur many hundreds of millions of times during a year on our roads causing vehicles to brake suddenly and sometimes maneuver suddenly (refer Figure 1 Motorway lane occupancy plot showing nucleation events - preconditions for crashes). Only a small number of these occurrences actually result in crashes, as usually drivers find just enough braking time or empty road space to avoid a crash often missing other vehicles by a matter of centimeters. When crashes occur they usually but not always result in "property damage only" crashes.

As can be seen in Figure 11 below "Events of Exposure" named as encounters in the graph do not grow linearly with growth in traffic volumes.[87] Increasing "Events of Exposure" per unit of time creates an increasingly complex driving task, causing more stress on drivers and when drivers are placed within increasingly complex situations they make more errors discussed in Section 7.4.2 *The problem of composite exposure*.

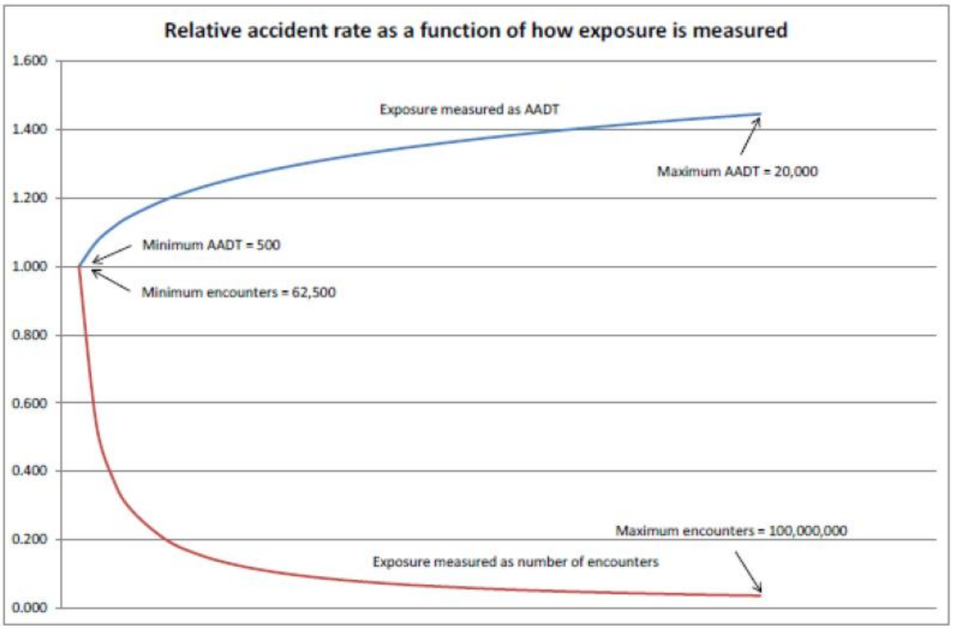

Figure 11 Shape of relationship between relative exposure and accident rate

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[87] Refer Figure 13 and Figure 21 in Section 7 Further Understanding the Motorway Safety Problem and Section 6.2 Events can be linked to a probability theory to crash risk .

7.1 Increased volumes increases crash risk

There is a direct link between higher traffic volumes, congestion and crash risk which has not been well understood. Higher traffic volumes generally makes the driving task more complex particularly on the higher speed and higher volume roads, where vehicles at times tend to bunch quite closely together,[88] which reduce safe distances between vehicles (known as spacing or headway[89]). The close distance between heavily trafficked lanes (lane keeping) also requires drivers to constantly judge blind spots and adjust speed to align with other vehicles both ahead and beside them, and to find suitable gaps and align with them when they need to change lanes.

As traffic volumes increase, even a small momentary lapse in concentration can result in vehicles wandering out of their lane leading to an increase crash risk particularly if motorcycles are lane splitting at high speed, (refer Figure 25 Vehicles event data displaying vehicles as particles revealing the lateral position in lanes). Under lower traffic volumes vehicles are not constantly driving alongside one another, these events have much lower crash risk as the increased available road space makes the road more forgiving and driver error becomes less noticeable.

When motorists are clustering in bunches the required driver reaction times to emergency brake is much less than the road was designed for. Sometimes the first thing the driver sees is the brake light of the immediate vehicle in front slamming on the brakes, giving the driver virtually no thinking time (reaction time) to avoid a crash.

Drivers need to concentrate much harder for much longer when driving on moderately heavy or congested, higher speed roads, a complex situation where the likelihood of increased human error and increased fatigue levels compromises safety. This problem may be amplified as motorists often drive in these conditions for longer distances, as most urban motorways have been progressively connected to rural motorways and highways, forming part of a continuous high speed and high quality connected road system, which at certain times can operate with traffic conditions that have a very high risk yet conditions may seem to be “Genteel or Buzzing” refer Section 5, An Explanation of the Complexities Involved in Motorway Operation.

Driving tasks that were considered to be straight forward for drivers under less congested conditions, are now increasing much faster than with the growth in Annual Daily Traffic Volumes (AADT). When motorists are placed under increasingly more complex and more stressful conditions for longer periods of time each day or for more hours of the year we should not be surprised to see increased “human error” leading to increased crash rates. This higher crash risk now occurs over much of the daytime hours on urban motorways, as traffic conditions typically reach around Level of Service (LOS) C conditions, which are the pre-conditions for the highest crash risk.

The connection between other urban and rural roads crashes should not be ignored. When drivers leave moderately to heavily trafficked motorways or highways, their concentration level is likely to fall sharply, because of the perceived less congested and less stressful situation. When their guard is down, crashes may occur on secondary or local roads. This is also because of other related behavioural issues which have been identified during the Churchill Fellowship, refer Section 12.3 Highway hypnosis and velocitation. “Highway Hypnosis” is where drivers who drive long distances can move into automatic pilot type mode, and drive without actually being aware of what is happening around them. “Velocitation” is when drivers get a sense they are travelling much slower than they actually are, when they move onto slower roads after a long period of high speed driving. Long stretches of motorway driving drivers may become vulnerable to crashes on other roads. We

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[88] Observations of motorway traffic and vehicle event data shows a pattern every few seconds i.e 20-30 seconds of traffic bunching and dispersing and bunching and dispersing etc

[89] Measured in both time (seconds) and distance (meters)

have seen a rapid increase in the length of rural motorways in Australia over the past 30 years and although they are safer, at the times when they have heavy traffic volumes they can be quite stressful or tiring to drive on for many motorists, particularly for drivers with limited motorway driving experience, and for those drivers who typically avoid[90] motorways, but have no alternative when traveling in rural areas.

7.1.1 “Chain reactions” as “Events as Exposure”

Usually when disturbances in traffic flow form they will immediately disperse within a few seconds. Hence they have not been typically detected in traffic data, or well described by traffic scientists. With the latest infrared traffic data collection systems, this phenomena can now be easily seen and measured with a high degree of accuracy, when larger events that sustain for 20-30 seconds or more are seen.[91]

At other times these perturbation[92] events can create a “chain-reaction” Figure 12 a slingshot or ripple effect[93] in the traffic flow. The first thing an unsuspecting driver sees is the brake lights of the immediate vehicle in front of them, and the first warning is that this vehicle appears to be braking extremely hard. The driver has little or no reaction time to brake and steer to avoid a crash. A “rear-end” crash is the most likely crash type (52%) caused by “Nucleation Events” and or “Shockwave Events”[94]. They can also cause a “side swipe” type crash (17%) as vehicles maneuver to avoid collisions or even a run-off-the-road crash (16%) as the driver swerves to avoid collision. What can also been seen in Figure 12 Heat plot’ from the Monash Freeway (inbound speed profile) are small isolated yellow patches where a perturbation has occurred without a resulting shockwave forming, refer also to Figure 1 Motorway lane occupancy plot showing nucleation events - preconditions for crashes.

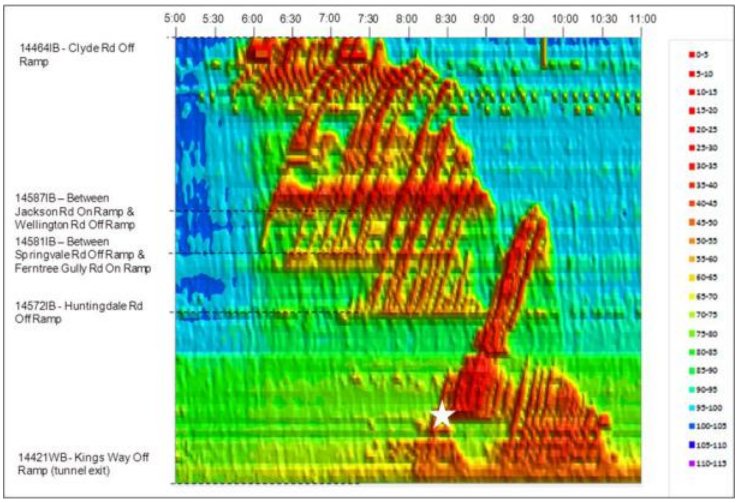

Figure 12 Heat plot’ from the Monash Freeway (inbound speed profile)

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[90] Anecdotal evidence emerged during the Churchill that many drivers self select not to drive on urban motorways due to their perceive danger and higher risk of crashes, however often when driving in rural areas these motorists do not have a choice

[91] Depends on where the disturbance occurs in relation to location of the detection devices installed in the roadway. If located close to the event even the short events are seen i.e. those lasting only a few seconds

[92] Nucleation events

[93] Only when the pre-conditions for shockwave formation exist in the upstream traffic flow – i.e. the various shockwave systems (5 different generic types – refer M Trieber) requires higher density traffic for them to form and/or to promulgate upstream against the traffic flow.

[94] Quite different mechanism – “Nucleation Events” only trigger “Shockwave Events” when they are very strong or when they are triggered when traffic density is such that a wave can form.

These perturbations are the cause of many of the urban motorway FSI crashes. A study of crashes on the Monash Freeway in Melbourne have shown a very strong correlation to these types of mechanisms e.g. conditions causing perturbations "Nucleation Events" and conditions causing "Shockwaves Events" are usually present before many of these crashes occurred refer Figure 13 where the crash is shown by a ★. Some vehicles types with a lower braking and maneuverability tend to be overrepresented in crashes.

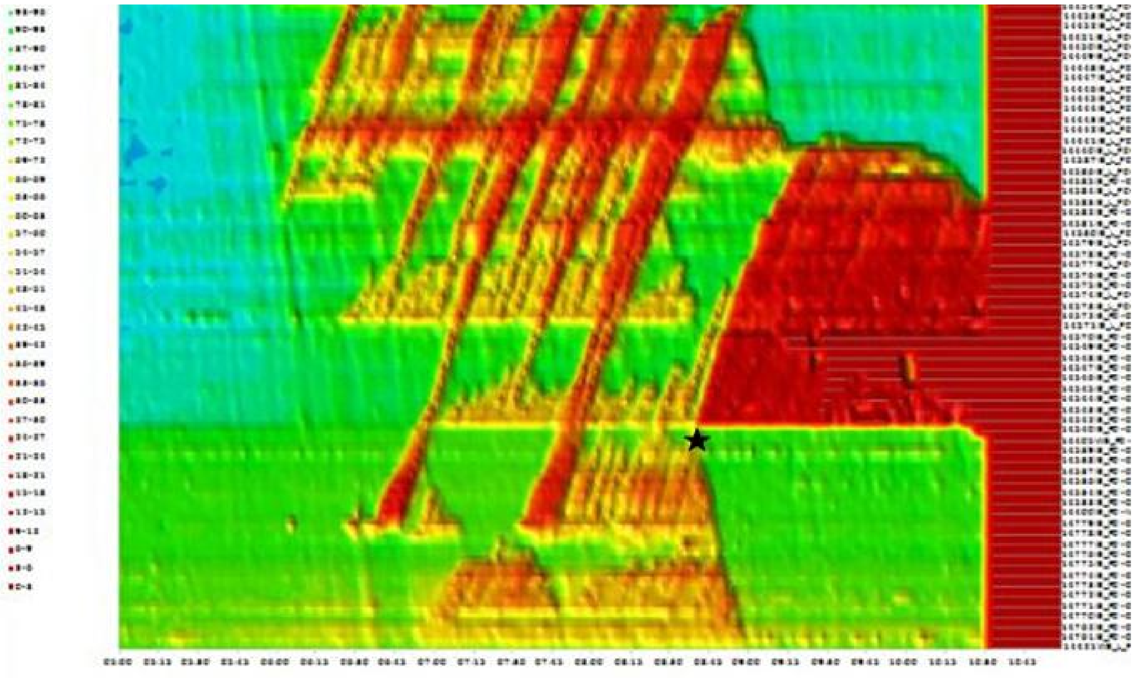

Figure 13 Graphical representation of speed data showing traffic conditions at time of a crash

These types of crashes create another complexity and dilemma for road safety researchers, as in many urban motorway crashes the vehicle(s) that triggers the crash, are usually not the vehicle involved in the crash, and the crash location is often separated by 100's meters upstream of the trigger point of the "Nucleation Event".

7.1.2 The changing nature of the motorway crash

A recent detailed study of motorway FSI crashes in Melbourne found a changing context of many road crashes: ***"Notably, the road infrastructure was not mentioned as a casual factor in any of the descriptions of these crashes by the Police. Instead, mention was made of heavy traffic, congestion and vehicle blind spots.***"

Another finding of this study of these crashes reveals that "***the great majority of casualty crashes involve vehicles crashing into other vehicles and the roadside infrastructure is generally not impacted with***". It is often hard to determine whether the road design or infrastructure is at fault (i.e. a geometric issue or a pavement maintenance condition at crash location), as urban motorway crashes are more often than not, indiscriminately dispersed, and causation can be shown to be systematic only when the crash is matched to the dynamics within the traffic flow.

Most urban motorway FSI crashes are vehicles crashing into other moving vehicles rather than vehicles crashing in to solid objects, which is an important insight into understanding these crashes as they cannot be described as necessarily being a geographic "Black Spot" location in the

traditional sense requiring infrastructure improvements. These finding provide new insights in to the ways we develop future models of crash causation and risk, and the solutions required to reduce the occurrence of the perturbations which triggered many crashes. **One US research study showed that 100% of flow breakdown events were caused by lane changing events (Ahn S, Cassidy M J) which are the key markers of a high crash risk.**

Obviously high standard infrastructure including safety barriers, are important for all motorways. However, as urban motorway collisions are more likely to be with other vehicles rather than hitting safety barriers, traditional infrastructure solutions may not be the best way to address these problems moving forward. In-vehicle applications such as Electronic Emergency Braking (EES) systems to decrease driver's reaction times, "Lane Keeping" Systems (LKS), "Blind Spot" Warning Systems as well as Smart Dynamic Variable Speed Limit (SDVSL) Systems are required to eliminate or reduce the crash severity. The safer vehicle component of the "Safe System Approach" needs tools and strategies for addressing these particular types of "Events of Exposure" to avoid crashes occurring.

7.1.3 The Safe System Approach on urban motorways

Urban motorways are well designed to prevent crashes compared to other roads. Higher design standards include greater separation between carriageways; central barriers to avoid head on collisions; and outer safety barriers to avoid run-off-the-road crashes and hitting solid roadside objects.

However, one of the complexities for urban motorways is the "potential for dangerous situations" to arise without obvious cues, or advanced warning, in the seconds leading up to the crash. Hence from Figure 87 Graphical representation of the "Safe System Approach" the categories "Deviation from normal driving", "Emerging situation" and "Critical situation" are not adequately separated in time and space as they occur almost simultaneously or within split seconds giving motorists little or no prior warning, making it difficult to provide solutions for. Also **these "Nucleation Events" and "Shockwave Events" create events of such severity that many drivers are not capable of undertaking, particularly when unexpected, and many vehicles on the road do not have adequate braking handling performance to stop safely, or undertake an emergency maneuver to avoid the crash** (refer Section 10 Are Vehicles Safe when Faced with an Emergency Stopping Situation?)

Generally motorists drive in a manner they perceive from experience to be safe, and at what is considered a safe speed and safe spacing,[95]and then suddenly a "chain-reaction" event is triggered in the traffic flow downstream out of their sight often five to 10 vehicles ahead of them.

The circumstance of these events means subsequent vehicles do not have sufficient reaction time and braking distance or maneuvering space to avoid the crash. This is explained further in more detail in following sections however this understanding brings a new focus on the "Critical Situation" shown in Appendix A, Figure 87 below as the reaction time is either zero or too small for a driver to react appropriately to avoid crashing. Usually when these severe events occur, drivers avoid the crash by finding a few extra square meters of empty road space. However in very rare events where the driver has nowhere to go, refer Figure 25, and a crash results.

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[95] refer Figure 23 Typical distributions of headways on an urban motorway

7.2 Events can be linked to a probability theory to crash risk

Rune Elvik, TOI, Norway in his paper titled "Towards a general theory of the relationship between exposure and risk" proposes a new definition describing commonly occurring traffic "Events of Exposure" to crash risk. The following section heavily quotes relevant sections directly from Rune's paper with quotes shown in *italics* and ***bold*** highlights have been added by the author. This type of thinking provides considerable wisdom and requires a fundamental shift in the way many road crashes are viewed, understood, and analysed. In particular, for urban motorways, it is possible to measure many of these "Events of Exposure" which grow at a much faster rate than AADT.

"Exposure is defined as any event, limited in time and space, that has the potential of becoming an accident and places demands on road user cognition. Events are countable; thus their total number can be regarded as a sampling frame (population) from which accidents are sampled with a certain probability".

Limited in time and space implies that these events may last only a few seconds at locations, which include a short length of road space from meters to tens of metres, (i.e. the time and place where a vehicle passes an oncoming vehicle, an overtaking maneuver, or where a lane change maneuver occurs on a motorway). Rune explains why **these definitions of exposure and risk, re-establishes the connection between the basic concepts of accident research and probability theory** a fundamental which seems to have been diluted over the past 30 years. This report is a reconnection with appropriate statistical methods towards "**a general theory of the relationship between exposure and risk**". It is in a way a first attempt to develop the key concepts of such a theory, and illustrates the importance of such a line of enquiry, providing many useful insights. **Rune's thinking and approach seems to have great relevance to the recent rises in crashes as "Events of Exposure" can explain much of the linkage, purely from the rising traffic volumes which increases these events disproportionately to increases in travel alone**[96]. For too long, many outdated assumptions and methods have been used by analysts. Rune's approach exposes commonly used metrics like the use of "crash rate" as not being an appropriate tool to control for the effects of exposure on the number of crashes*.*

7.3 Problems with the conventional concepts of exposure and risk

"Historically, the key concepts of accident research, exposure, and risk were derived from the concepts of trials and probability, as defined in the field of probability theory. A trial was any random event that had an accident as one of its outcomes. The probability of an accident was the proportion of trials that had an accident as its outcome. ***Modern summary measures of exposure, like AADT, annual driving distance or vehicle kilometres of travel, cannot be interpreted as trials in the classic sense of the term. The commonly used indicator of risk, accidents per million units of exposure, cannot be interpreted as a probability and may not even be positively related to it. Thus, as conventionally used today, the concepts of exposure and risk have lost their connection to probability theory".***

"This means that one cannot assume that the product of exposure and risk produces unbiased estimates of the long-term expected number of accidents. In particular, ***the increasing understanding that risks are non-linear (i.e. depend on the amount of exposure) completely invalidates the use of accident rates to control for the effects of exposure on the number of accidents".***

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[96] i.e.increases is Annual Average Daily Travel (AADT)

7.4 Defining events and learning from these events

Rune proposes new definitions of exposure and risk. *"**Exposure is defined as any event, limited in time and space, that has the potential of becoming an accident and places demands on road user cognition**. This is considered to be a very important factor usually overlooked that **drivers do learn from exposure just like a sportsperson who trains regularly progressively learns how to respond more efficiently to certain situations."***

*"The latter part of this definition, **referring to human cognition, is not normally part of the definition of exposure, but has been included because any event producing the potential for an accident is the result of human behaviour** and requires action by road users to control it so that it does not become an accident."*

*"Events have limited duration and spatial extent. Their beginning and end can be defined precisely enough to allow events to be counted. **The total number of events can be regarded as a sampling frame (population) from which accidents are sampled with a certain probability. The risk is thus defined as the proportion of events that have an accident as the outcome.**"*

"Events generate a potential for accidents by bringing road users close to each other in time and space, or by requiring the road user to take action to avoid leaving the roadway". (Rune)

The following elementary types of events are proposed in Rune's paper and this understanding closely aligns with recent motorway crash research revealing that crashes are related in time and space to conditions encountered:

- *Encounters, i.e. vehicles or road users passing each other in opposite;*
- *Direction of travel with no physical barrier to separate them;*
- *Simultaneous arrivals at points where conflicts between road users may arise (junctions, pedestrian crossings);*
- *Turning movements in junctions (involving road users who did not necessarily arrive at the same time);*
- *Braking events;*
- *Lane changes on multi-lane roads;*
- *Overtakings, i.e. one vehicle passing another vehicle travelling in the same direction; and*
- *Negotiating horizontal curves.*

*"**An event typically last a few seconds**. **For some of the events listed above, their number can be calculated from summary measures of exposure, like AADT**. In the future, however, it is likely that motor vehicles will have technology that can recognise the events and be able to count them if the technology for this purpose is part of the event-recognising systems. There is already in the market vehicle technology that monitors braking (intelligent cruise control), lane-keeping (related to encounters and running-off-the-road) and blind spots when changing lanes."*

*"These systems are probably only the beginning of more comprehensive, integrated systems that can monitor most aspects of traffic. **To redefine exposure in terms of specific events is therefore future-oriented and allows for a vastly more detailed study of exposure than current summary measures, like vehicle kilometres. Vehicle kilometres are, essentially, a black box and tell nothing about what happened along any kilometre driven.**"* Thus measuring these events needs to form part of future

crash-related data and analysis because if we don't measure and understand the events we will not understand when rates begin to rise.

"The repeated experience of a certain type of traffic event will be associated with learning, i.e. road users will become more and more competent in understanding and controlling the events so that they do not result in an accident. ***In general, therefore, one would expect there to be a negative relationship between exposure and risk. The larger the number of events of a given type, the lower the risk of accident.*** *Hence, even when exposure and risk are redefined as proposed in this report, it will, in general, not be correct to estimate the expected number of accidents by multiplying exposure with risk".*

"By contrast, the non-linearity of the relationship between exposure and risk must be modeled explicitly. The main task in developing a general theory of the relationship between exposure and risk is to propose specific hypotheses regarding the shape of this relationship."

7.4.1 Traditional measurement of crash rates have weaknesses

"There are two problems in using accident rates... in order to control for the effects of differences in exposure on the number of accidents. ***The first problem arises from the fact that accident rate is not independent of exposure, but tends to decline as exposure increases****. This tendency is most clearly evident in driver accident rates, as shown in several studies (Massie et al. 1997, Hakamies-Blomqvist etal. 2002, Fontaine 2003, Langford et al. 2006, Alvarez and Fierro 2008). Thus in the study of Hakamies-Blomqvist et al. (2002), accident rates for drivers aged 26-40 years were:*

- *72.4 accidents per million km of driving for drivers whose mean annual driving distance was 1,272 km;*
- *14.7 accidents per million km of driving for drivers whose mean annual driving distance was 8,497 km;*
- *5.8 accidents per million km of driving for drivers whose mean annual driving distance was 25,536 km."*

"These accident rates cannot be interpreted as estimates of the probability of accidents. ***The probability of becoming involved in an accident is not even positively related to the accident rates.*** *The mean annual expected number of accidents can be estimated to 0.092 for low-mileage drivers, 0.125 for middle-mileage drivers and 0.148 for high-mileage drivers (estimated by multiplying accident rate by annual mileage). If the assumption is made that accidents occur according to the Poisson probability law, the probability of becoming involved in at least one accident during a year can be estimated to:*

- *0.088 for drivers who drive a mean annual distance of 1,272 km;*
- *0.117 for drivers who drive a mean annual distance of 8,497 km;*
- *0.138 for drivers who drive a mean annual distance of 25,536 km."*

In other words, as exposure increases so does the probability of becoming involved in an accident, but not in proportion to the number of kilometres driven.

7.4.2 The problem of composite exposure

*“**The second problem in computing and using accident rates arises in the case of composite exposure, i.e. exposure consisting of two or more traffic movements that both contribute to the risk of accident.** Examples include pedestrians crossing the road (both the number of pedestrians and the number of vehicles contribute to the risk) and turning movements conflicting with traffic going straight ahead in junctions. Hauer (2004) illustrates the problem in discussing the effects on safety of providing left turn phases at signalised junctions. The number of accidents involving left-turning vehicles depend both on the number of vehicles turning left and on the number of oncoming vehicles going straight through the junction. Hauer shows by means of an example that if exposure to the risk of a left-turn accident is estimated by using the number of left-turning vehicles to measure exposure, permissive/protected (lagging) phases (i.e. a left turn signal comes on at a time when the opposite traffic stream still has a green signal) have a lower accident rate than protected/permissive (leading) phases (i.e. a left turn signal comes on when the opposite traffic stream still has a red signal but continues into the green phase). If the sum of left-turning and straight-ahead vehicles is used to measure exposure, leading and lagging phases have identical accident rates. If the product of the two traffic movements is used to measure exposure, leading phases have a lower accident rate than lagging phases. The problem is that it is not obvious which of these measures of exposure, if any, that most correctly reflect the opportunity for accidents to occur.”*

This work can be expanded to include composite “Events of Exposure” on urban motorways where simultaneous events can occur such as high-density traffic and higher speed, combined with lane changing on a tight horizontal curve with a 15% heavy vehicle content.

7.4.3 Defining exposure as events

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

- *Encounters;*
- *Simultaneous arrivals from conflicting, or potentially conflicting directions of travel;*
- *Changes of direction of travel close to other vehicles or road users; and*
- *Braking or stopping.*

It was shown how the number of events can be derived from summary measures of exposure, such as AADT by means of simple mathematical models. Below, examples are given for encounters and simultaneous arrivals (arrivals within the same second) in junctions. For the other types of events, see the paper by Elvik, Erke and Christensen (2009).

Encounters are the passing of vehicles travelling in opposite directions. Each encounter represents an opportunity for a head-on crash on an undivided highway. On divided highways, head-on crashes are still in principle possible, but the opportunities are greatly reduced (Martin and Quincy 2001). The number of encounters on an undivided road equals: If AADT is known, the number of encounters expected to occur at any point on the road can be estimated for any period of time by dividing AADT by 2, and further dividing by, for example, 24 to obtain mean hourly volume. The number of encounters is obtained by raising the number of vehicles passing a point in both directions, divided by 2, to a power of 2.

The number of encounters increases considerably faster than AADT. If, for example, AADT increases from 1,000 to 10,000 (a factor of 10), the number of encounters increases from 250,000 to 25,000,000 (a factor of 100). This has major implications for the shape of the relationship between exposure and accident rate. According to an accident prediction model (Fridstrøm 1999), the number of multi-vehicle accidents increases in proportion to AADT raised to a power of 1.1 (AADT1.1). If the rate of accidents (number of accidents divided by AADT) is plotted as a function of AADT, it will slope upwards. If on the other hand, the rate of accidents is plotted as a function of the number of encounters (number of accidents divided by number of 4 encounters), which is proportional to (AADT/2)2, it will slope downwards. This is shown in)Figure 11 Shape of relationship between relative exposure and accident rate), (Elvik 2010)".

"With respect to simultaneous arrivals in junctions, the number of arrivals within the same second also increases considerably faster than AADT. If hourly entering volume from all approaches in a three-leg intersection increases from 200 to 2,000 (a factor of 10), the potential number of conflicts per hour (arrivals from more than one approach within the same 1-second interval) increases from 4 to 298 (a factor of 83). Since the number of events representing a potential conflict increases at a much faster rate than traffic volume, as measured by AADT, the shape of the relationship between the number of events and the number of accidents will be different from the shape of the relationship between AADT and the number of accidents.

7.4.3.1 Exposure as learning

"When exposure is defined as events, it follows naturally to think about exposure as a process of learning. The shape of the relationship between exposure and risk is therefore influenced by the efficiency of learning that repeated experience of given events provides. The idea that exposure can be regarded as a form of learning is not new. Reason (1997) presents information regarding the probability of making errors when performing tasks with a given description. Table 4 Probability of making errors when performing certain tasks - adapted from Reason *shows the tasks and the estimated error probability for each of them. The probability of error equals the number of times an error was made divided by the number of times the task was performed.*

It is seen that the probability of making an error is very high when the task is unfamiliar but declines to a very low level when a task is familiar and the system supports the operator in performing the task".

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

Table 5 Probability of making errors when performing certain tasks - adapted from Reason

"Until recently, observing how frequently road users, in particular car drivers, commit errors has been difficult. Naturalistic driving studies now make detailed observation of driver behaviour possible. Although good statistics does not exist, it seems clear that the reliability of human operators in road traffic is very high. ***Very few of the events that represent an opportunity for an accident result in an accident.*** *In some cases, errors may nevertheless have been made, but there is a margin for error recovery, giving the road users a chance to correct the error before an accident occurs. Events are opportunities for learning".*

Very often driver errors are also corrected by other motorists and road users who observe the error(s) being made and take evasive action by braking or stopping or getting out of the way to make allowance for the error thus avoiding an incident, hence most crashes are avoided as a result of collaborative behaviours or "informal interventions" by others which may also be "Learning as Exposure" described below.

"It is reasonable to assume that events differ with respect to their potential for learning. In some cases, a single exposure to an unwanted event may be sufficient to prevent its repetition. Thus, a novice driver who neglects to check the blind zone when attempting to change lane, and to his or her great surprise discovers that there is a car in the blind zone, will probably find the experience so unpleasant, and the nature of the mistake so obvious, that it is unlikely to be repeated. This is a case of single-trial learning.

Other events are more subtle and give fewer clues about how to manage them. Judging speed and distance can be difficult and it may not always be clear whether there is time enough to turn left in front of an oncoming car or not. *In general, learning from specific events is facilitated if:*

1. *The event only requires a simple action (the complexity of the event). Simple actions and tasks are easier to learn than more complex actions and tasks.*
2. *The frequency of the event. Events that occur often give more opportunities for learning than events occurring rarely.*
3. *The similarity of repeated instances of the event. Events that are completely identical each time are easier to remember and learn than events that differ in some of their characteristics.*
4. *How quickly an event unfolds. Events that require very fast action are more difficult to manage successfully than those that develop more slowly. The shock and surprise of a very fast event may block effective learning from it".*

Motorway "Nucleation Events" and "Shockwave Events" whilst very common with many thousands of such "Events as Exposure" each day, the circumstances under which each one occurs varies greatly. Often the outcome is a result of the speed the event occurs, or the amount of spare road space. The experience of the individual driver, is that 99 out of 100 times when these rare events occur over their entire driving life[97], there are no consequences except extra hard braking, hence there is no consequences perceived, and hence little or no learning from experience. Each driver may only encounter a heavy braking event once or twice a year all of which were uneventful having no long term impact on their driving behaviour.

"In addition, to these characteristics of events, it is essential to remember that learning is strongly

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[97] At the individual driver level these events may only occur once every 3-6 months

guided by motivation. If it requires too much effort to learn something, if it is experienced as too difficult, motivation is reduced and learning becomes less effective. With respect to road traffic, the concept of motivation can perhaps not be interpreted in exactly the same sense as in learning theory, but the mechanism operating is closely analogous.

There is, up to a certain limit, behavioural adaptation to perceived skill. ***Thus, a driver who regards himself or herself as highly skilled may decide to drive at a closer distance to the car in front than a driver who has less confidence in his or her capacity to react quickly should the car in front suddenly brake.*** *The limits of behavioural adaptation are, broadly speaking, set by the interaction with other road users and the environment. In dense traffic, you may choose a shorter headway than most other drivers, but you cannot choose a different speed. Likewise, when entering a busy road from a minor road, there are limits to how long you are willing to wait for a gap in traffic while the queue builds behind you. At some point, you just have to dash into the main road, perhaps recognising that the margin is a little tight, but counting on drivers to "let you in" by slightly slowing down.* ***Most of the time, these informal conventions work out fine, but sometimes they break down and an accident occurs."***

7.4.4 Drivers are slow adaptors accepting reduced margin of error in adverse conditions

"Adverse environmental conditions also impose limits on behavioural adaptation. In heavy snow at night on an unfamiliar road, a safe driving speed may be, say, 30-40 kilometres per hour. Yet, such a drastic behavioural adaptation is felt as excessive by most drivers. Drivers do slow down, but not enough to maintain safety margins. There is a trade-off between adding travel time and adding to the safety margin. ***Most drivers probably realise that they are not adapting enough to adverse weather, but prefer to accept a reduced safety margin*** (Bureau, 2006) (Elvik, Towards a general theory of the relationship between exposure and risk, 2014).

As discussed Section 10.9 (Are wet, dry, damp or hot pavements problematic for motorists?) damp pavements, mist or fog combined with medium to high traffic volumes may result in a very high crash risk and there is not enough adaption or adaption is too slow, as the risk is neither seen by motorists as excessive, or maybe not even recognised as an increased crash risk. This may be the case when the heavy dew has settled on the pavement, after a long dry spell, and the often bright sunshine is also present due to clear Australian skies and this may give the false impression of a low crash risk. Thus the shape of the relationship between exposure and risk is not just determined "Events of Exposure" and learning only, but also by the extent of behavioural adaptation when the adverse condition arises.

7.5 Further understanding of these relationships for urban motorways

It was also noted from Rune Elvik **(Elvik, Speed and Road Accidents - An evaluation of the Power Model) that increases in "mean speed" increases crash outcomes. VicRoads' work on urban motorways reveals a much stronger relationship between traffic density and serious casualty** crashes rather than simply speed alone. This divergence needs further consideration and investigation particularly in the urban motorway context[98]. Serious casualty crashes tend to occur at average carriageway speeds 15-30km/h below the posted speed limit when average traffic density begins to rise quickly and/or vary rapidly (measured at the 1 minute or higher resolution), with moderate traffic volumes, and when traffic in the carriageway collectively has begun to slow down.

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[98] This is discussed further in Section 14, Motorways Speed Management for Efficient and Safe Operations

However there appears to be other extensions to Rune’s work not taken into account, as one of the major ”Events of Exposure” involves increasing lane changing as the motorway carriageway begins to fill up all the remaining roadspace. These events have the effect of increasing momentarily the point densities within the traffic stream, as vehicles move between the lanes and at least momentarily creating smaller gaps between vehicles as vehicles move into smaller gaps momentarily dividing the space until drivers adjust their spacing by braking or accelerating. Another event is when a “Traffic State” suddenly changes creating higher densities and smaller gaps (measured in both time and space). When lane changing results in sudden braking in heavy traffic flows, or a “Traffic State” change occurs, these are particular problematic types of ”Events of Exposure”.

In summary, Rune Elvik felt that many motorway safety problems will be difficult to solve in the future, as lane changes must be made quickly without hesitation with very short headways. Under these conditions human capability is pressed to the limit and machine capability is not currently adequate to improve on this[99]. However what we must do is crash analysis to understand the many factors involved, and this will reveal that traditional approaches to road safety and “black spot” analysis such as crash rates and traffic exposure (ADDT) may no longer provide reliable understanding of the context of many road crashes and their associated risks.

Traditional before and after studies of crashes are often assumed to be positively related to exposure when research shows there are many other confounding factors at play within the road environment and the traffic stream. Rune’s **insights and** definitions of exposure and risk “**re-establishes the connection between the basic concepts of accident research and probability theory” that need to be examined in** road safety analysis.

7.6 Human error as “Events of Exposure”

It is well established that “human error” is involved in 95% of road crashes), however these are generally but not correctly seen as rare events. This is because:

- most errors are corrected by the driver themselves or nearby drivers who brake and steer to avoid crashing with the vehicle making the error, and
- larger errors are corrected by the road environment where there is enough time and space for vehicles to safely recover.

In addition to the large number of “human errors” that do not end in crashes, there is:

- a much smaller number of events that end up as “property damage only” crashes which are no longer recorded in police records
- an even smaller number of events that end up as “minor injuries”,
- an even smaller number again that end up as “serious injury” crashes, and
- a minute number that result in fatality crashes.

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[99] Often autonomous vehicle analysts make assumptions based on average time headways i.e. 1.6 or 1.8 seconds and do not understand that lane changing headways are often as low as 0.3 seconds and are made into gaps which are quite small i.e. 2 vehicle lengths e.g. 10m. Any faster lane changing than vehicles currently do, may prove to be very uncomfortable for the average driver and their passengers as they will have to experience higher sideways forces. Also road geometry in the urban context presently in many cases does not safely allow for higher motorway speeds with is often assumed to be solution to the lane changing problem by increasing gaps size and thus this is often modelled as such without any acknowledgement of well established road design principles and physical forces linked with driver comfort levels associated with higher speeds, generally requiring the road to be redesigned.

The following Figure 14 Driver error categories - illustrating the limited available research data, is an attempt to illustrate that when it comes to understanding the nature of the "human error" problem we really have very limited "post crash" data and very little "pre-crash" data. In Europe it seemed promising that this data shortfall was starting to be corrected in a number of the research centres visited as part of the Churchill Fellowship.

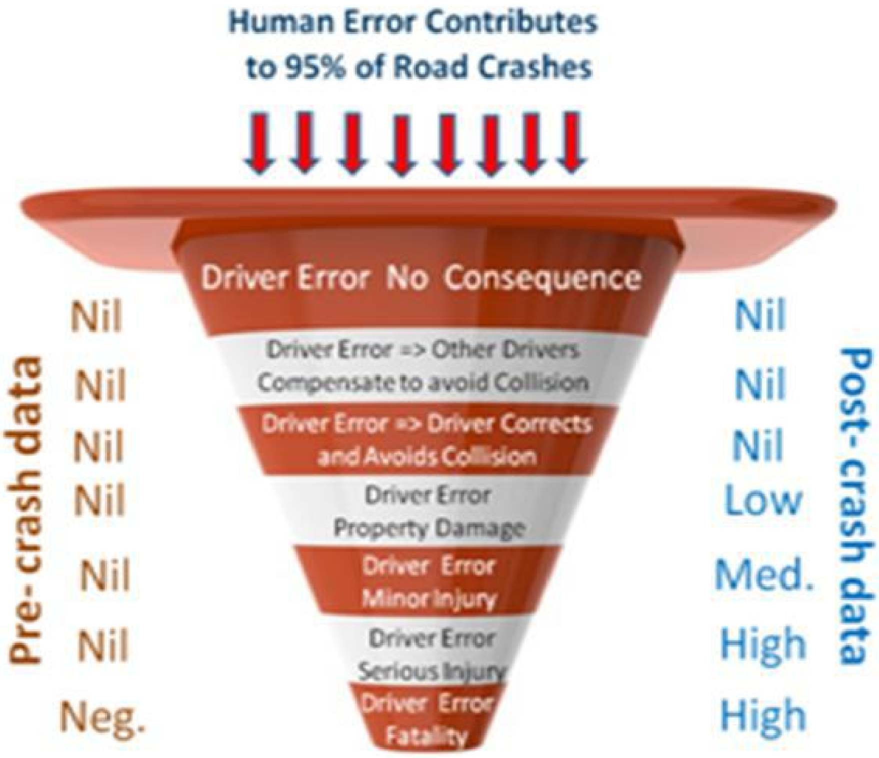

Figure 14 Driver error categories - illustrating the limited available research data

7.6.1 More data is required to understand mechanisms

Crash cause or its consequences depends on many unique features such as:

- the state of the driver or level of alertness,
- traffic conditions at the moment of a crash,
- whether an animal jumped in front of the vehicles,
- whether the vehicle's tyre punctured,
- the exact location where the error occurred (e.g. spare roadspace or hard shoulder or crash barrier),
- the vehicles involved safety performance (i.e. age, types and safety features, braking and maneuverability),
- pedestrians' age, fragility and physical condition,
- the vehicles impact zone(s), and
- the part of the human body that forces were transferred (i.e. head, torso or leg etc).

The underlying difference between a "human error" not resulting in a crash, and resulting in a fatality is what some may describe as chance, as many unique factors combine within split seconds.

Crash outcomes are very dependent on the circumstances occurring at the moment of the crash such as:

- the temporal traffic conditions (not AADT),
- the decisions and actions made by the driver,
- how much spare road space was available (margin for error),
- fatigue levels and level of alertness or
- capability of the driver.

Often the difference between no collision and a fatality crash comes down to only a few centimeters (20-30cm where they missed an object or another vehicle before they could slow to a lower impact speed with more favourable outcomes).

Each crash is unique and the majority of researchers interviewed during the Churchill Fellowship, indicated they do not have access to enough data to understand the unique nature of individual crashes. We therefore tend to classify crashes into logical categories (refer section on Narration Bias in Section 10 below), where humans like to simply group information into explainable stories based on observable patterns. Traditional data sources were good for identifying "Accident Black Spots" locations, where large numbers of similar crashes accumulated at a single location. However these days a much higher percentage of crashes appear to be indiscriminately dispersed. Even when there are clusters of crashes at a single location they are often not of similar type or cause, and most fatalities crashes generally occur at different locations every time, with no previous crash history of fatalities or serious injuries.

What became clear during the Church Fellowship is that road crashes are extremely rare and unique events, and are the results of billions of interactions or events. Crashes can occur anywhere at any time. Where the next road fatality or serious injury occurs statistically is unlikely to occur at a location where there has been a significant crash history particularly in the past 5 years[100] Refer to the AustRoads report SAG2090 quoting crashes in Auckland, New Zealand where in 2013, 79% of the fatalities and serious crashes occurred at sites with no fatal and serious crashes in the past five years, and 64% of crashes occurred at sites with fewer than two injury crashes in the same five year period.

Reducing crashes on motorways involves understanding the complex matrix of crash pre-conditions within time (seconds) and space (metres) such that we see small clusters of vehicles bunching within the carriageway. Future road safety strategies and programs need to build upon the excellent research already done and extending this work to accommodate a new understanding of "Events as Exposure" which provides a basis to link crash risk to probability theory. These concepts are expanded further in Section 8, Further Understanding the Motorway Safety Problem below

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[100] Refer AustRoads report on road safety for New Zealand fatalities

8 FURTHER UNDERSTANDING THE MOTORWAY SAFETY PROBLEM

As discussed in Section 7.2 (Crash Risk a Function of "Events of Exposure"), the motorway safety problem involves many complexities resulting often in many different factors coinciding in time and space , of which many can now be measured at small discrete time intervals of usually 20 second or less, and space, within the width of an individual lane or within a motorway carriageway's cross-section. The Swiss cheese model, first proposed by James Reason, shown in Figure 15 below, highlights that there are usually many contributory factors to crashes and many of these factors align before a crash occurs.

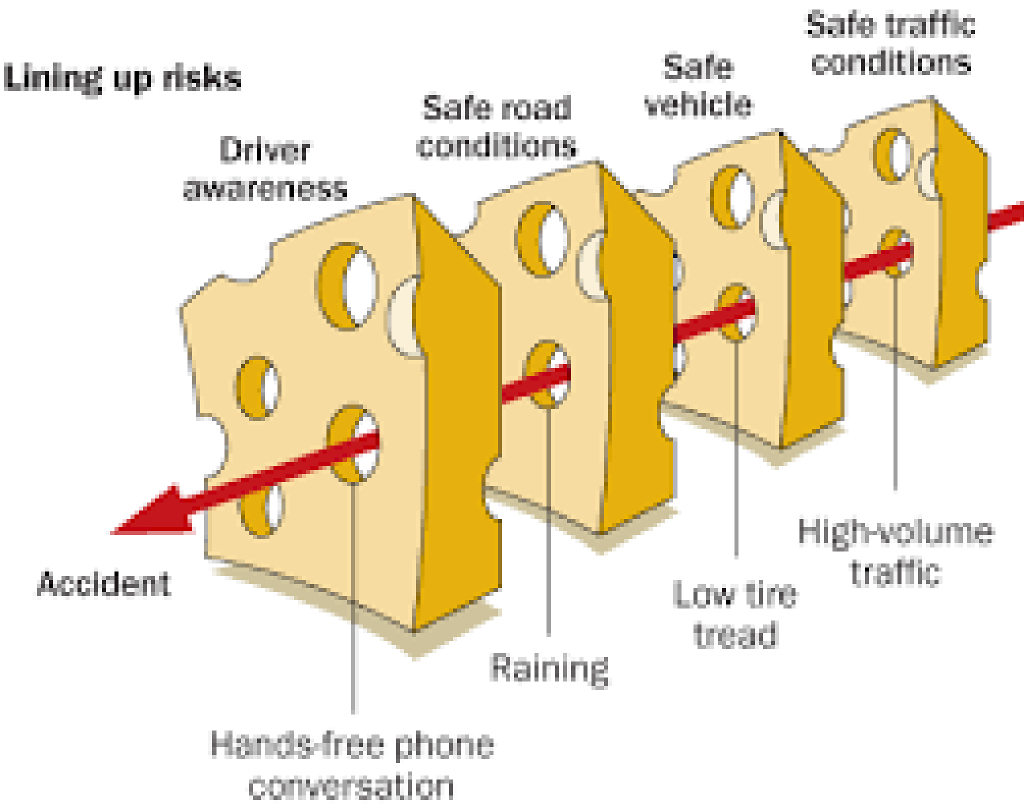

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Figure 15 The Swiss Cheese Model proposed by James Reason

The Swiss cheese model illustrates the complexity of the road safety problem, however, in the example shown above we can see some suggested risk factors as these may or may not be involved in any particular crash. Of course there are many other factors (e.g. human error, driver capability, driver fatigue levels, vehicle design limitations including tyres, brakes and vehicle handling performance, road pavement conditions, nearby hard roadside obstacles such as trees, and debris), and other environmental conditions as well as the reaction of other drivers in the vicinity. Thus many factors often combine in some way to form a "Critical Situation" in the moments before the crash refer Appendix A, Figure 87 Graphical representation of the "Safe System Approach.

8.1.1 Crashes are very rare events

Fortunately crashes usually do not occur often, primarily because of all the limitations (i.e. holes in the cheese), do not necessarily occur simultaneously in time and space. Thus drivers tend not to be involved in crashes, or more correctly mostly potential crashes are avoided by corrective action as usually the driver or one or more other motorists take evasive action, which avoids the potential collision and usually there is sufficient time and space to avoid the collision.

However, based on probability theory (i.e. chance that comes from high occurrences of certain "Events of Exposure") described in Section 7 above, these holes sometimes unfortunately align. An example of the high level of exposures on urban motorways is that a single motorway Melbourne's M1 motorway has approximately 5.5 billion kilometres of travel per annum, a travel distance of over 30 times to the sun or 15 million kilometres every day of the year. This equates to the distance from Melbourne to London, a distance of about 15,000 km being travelled on average every 90 seconds of the year.[101] A fatality crash occurs in Australia on average once in 192,000,000 kilometres of travel, a distance much greater than travelling to the Sun. Therefore with such large amounts of exposure to the risk, we should not be surprised that the holes in the "Swiss Cheese" occasionally align resulting in crashes.

However the nature of these relatively rare crash events means crashes are usually randomly dispersed (i.e. do not generally occur at the same locations), and this is why it is often hard to generalise about linking motorway crashes (or any crash) to certain geographic locations or road features or road type, particularly, if their sample size is very small (i.e. less than 5 crashes in 5 year period of the same type). Often crashes are separated by 100's or 1000's of metres spatially, as road safety analysis and programs have traditionally done when classifying crashes into "Black Spots" or "Black Lengths" by association of crashes with simple patterns[102]and linking these with specific geographic road segments.

Many types of crashes are not systemic to spatial location but rather appear to be systemic to certain "Events of Exposure" and thus many road crashes should be considered to be a network-wide problem, where coinciding events (i.e. alignment of "holes in the cheese") could occur anywhere at any time and hence are not unique to a particular geographic location or even road type. **As some types of crashes occur whenever certain problematic conditions coincide, road safety solutions need to be developed that manage and reduce the likelihood of the crash pre-conditions occurring.** These solutions may include further improvement to the vehicle fleet (i.e. stability and handling, braking, safety applications that travel with the vehicle), educational programs and traffic operations (e.g. traffic control and warning messages) that provide network-wide safety by making motorists aware when crash risks may be elevated, and supporting them in their decision making and in the driving task.

8.2 Examples of the complexities involved in crash causation

There are specific traffic conditions that must occur before there is a high likelihood (risk) of a crash occurring on motorways. These same factors also impose very high mental demand on drivers requiring their full concentration without distraction and, when a disturbance (i.e. a perturbation, event occurs in the flow), it usually requires the driver to make a split-second decision to enact an appropriate crash avoidance action (e.g. a rapid steering maneuver and severe braking to avoid those vehicles around them and other hard infrastructure such as traffic barriers. Usually, the driver is alerted and sees these events unfolding in front of them and they react appropriately by covering the brake pedal, however, some of these events occur out of their range of vision (e.g. line of sight or from within their "blind spots") or before they have a chance to check their mirrors.

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[101] To explain this phenomena refer Figure 10 Daily profiles of trips on M1 Motorway (15min). In most of the day this motorway has about 50,000 vehicles travelling about 1km at least every 40-60 seconds and this equals at least 50,000 km each minute for >12 hours a day

[102] Humans identify with patterns refer Appendix C Section 1.6 The problem of narration bias

8.2.1 Split-second decision making

During these split-second events, a large number of driver decisions and driver actions must be made. For example the driver may be driving at what is deemed to be a safe distance behind the vehicle in front of them in an apparently light traffic conditions, as the motorway can look relatively empty even when loaded with moderate to high traffic volumes, there is an average of 30-40m spacing between all vehicles when a motorway operates at optimal capacity. During this moment the driver might be:

- following a larger vehicle restricting their sight distance,
- experiencing early morning sunny conditions and may not be able to comprehend that on this day the pavement is slightly damp caused by a heavy overnight dew which requires in this instance an additional 10-20m stopping distance.
- driving a vehicle fitted with aftermarket products which may include larger wheels and different tyres and/or modified suspensions[103] and 4WD tyres suitable for off-road driving which may be less compatible with driving at highway speeds, and often incompatible with the factory fitted ESC system supplied when the vehicle was new.

Furthermore slow or poor decision making or delayed by another distraction in regards to a motorist assessing the temporal risk of road traffic conditions, the road pavement conditions and the vehicle's handling and braking performance combine to determine the safety outcomes when an emergency braking or steering maneuver is suddenly required[104] a relatively common occurrence on motorways and other roads occurring many thousands of times each day.

8.2.2 Increasing vehicle size may be a significant contributor

During the Churchill Fellowship it became clear that larger vehicles, both heavy and light trucks and the larger four-wheel-drive vehicles[105] which are now occurring in increasing numbers on the Australian urban motorways are exacerbating the temporal time and space problem by further restricting the sight distance of following vehicles (i.e. both smaller and larger vehicles), reducing reaction times and thus margins of safety. The increased presence of these vehicles requires increased alertness of motorists particularly as the "Traffic State" can change within fractions of seconds and, driver's vision may be obscured from what is occurring just 50-150m ahead of them[106]. There also may be other vehicles in their temporal "blind spots" or in their potential maneuvering space and thus potential "rear end" crashes can suddenly turn into "sideswipe" crashes.

Often the trigger event for the crash and crash location are also separated in time and space. It has become evident from data and traffic theory that the causes of motorway crashes often involves faster drivers 8-10 vehicles ahead in the traffic stream, often with poor decision making, or who are tailgating, suddenly braking or making a harsh lane change maneuver. This sets up a "Chain Reaction" often resulting in following vehicles which are usually slower vehicles, with safer driving behaviours, crashing because they have no visibility of the disturbance in the traffic flow and little or no reaction time to avoid a crash.

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[103] Often which raise the vehicle's centre of gravity

[104] Many of these details are not being recorded when crashes occur but are vital to understand crash causation

[105] These vehicles also have quite different braking and handling performance discussed in Section 10(Are Vehicles Safe when Faced with an Emergency Stopping Situation?).

[106] Refer section 10.9 Are wet, dry, damp or hot pavements problematic for motorists? This section identifies issues related to stopping distances of vehicles operating at motorway speeds

The mechanism for this type of very common crash causation mechanism is clearly evident in contemporary traffic flow modeling work undertaken by Dr. Martin Treiber, Technical University of Dresden. Hence the trigger (i.e. the cause), and the symptoms (i.e. the crash), can be shown to be separated in time and space often separated by 100's metres upstream of the trigger point, making the crash problem difficult to comprehend and determine cause and thus difficult for researchers to quantify and understand without the availability of high resolution and high accuracy traffic data. Police records will usually determine responsibility for the crash, based on their interpretation of road laws which is no longer considered adequate in many cases, to understand the actual cause such that successful solutions can be developed.

The "Chain Reaction" event in the form of a backward moving shockwave travels in the opposite direction to that which the vehicle travel. A shockwave will typically travel at 18 to 24km/h backward the direction of traffic flow on the motorway. Within the shockwave, the gaps in the traffic between vehicles become momentarily very small (i.e. the traffic compresses) and it is this increased density with the traffic flow that enables the wave to keep promulgating upstream before it suddenly arrives and an unsuspecting driver will not be able to stop in time.

8.2.3 High-resolution data reveals detail of crash causation

Fortunately "Managed Motorway" data is now providing new insights into the circumstances of the crash as the traffic speed, volume, density and other metrics of traffic can be measured precisely in each lane both upstream and downstream of the crash location in the minutes or potentially now seconds[107] before the crash occurred. This data clearly shows that the spatial locality of the crash or geometry of the crash site is now considered to be potentially of less importance than the prevailing traffic conditions occurring at the exact moment of the crash.

This new information requires a major revision to how road safety analysis is carried out in Australia, as very little road safety analysis has studied the relationships between the temporal (i.e. sub 1 minute traffic flow dynamics) and road crashes, including on both urban and rural roads which also experience at times the same temporal conditions, with high traffic flows at higher speeds resulting in high density vehicles clusters (i.e. at points) described as "Nucleation Events". Refer Section 9. Innovative Australian technology (i.e. vehicle event data), is providing high resolution of "Events of Exposure" such as lane changing and braking and acceleration events. Hence traffic data in real time and historically is revealing new insights and confirming "Events of Exposure" are present in the moments before most urban motorway crashes occur.

8.3 The devil is in the detail

There is an old adage "Great fleas have little fleas upon their backs to bite 'em. And little fleas have lesser fleas, and so ad-infinitum" (Siphonaptere), which suggests when we look deeper with a microscope we can see more detail and, in the case of little fleas they bite the backs of bigger fleas. So it is with traffic flow theory as a study (Ahn S, Cassidy M J) observed that 100% of bottlenecks in their research project on a USA freeway, were triggered by lane changing events. Figure 16 Indicative lane change ratios to service a single point on a motorway with different lane numbers.[108,109]

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[107] Depends on how close the crash occurs to the detection point typically spaced at 500m intervals

[108] Note a 6 lane motorway requires triple (75,000) lane changes to service a single point on a motorway compared to a 3 lane motorway (25,000). Half the lane changes are required to load the point and the other half are required to unload the point. The lane changes are the minimum required to enter, travel along and exit the motorway filling each lanes to equally capacity. Note the left (blue) or slower

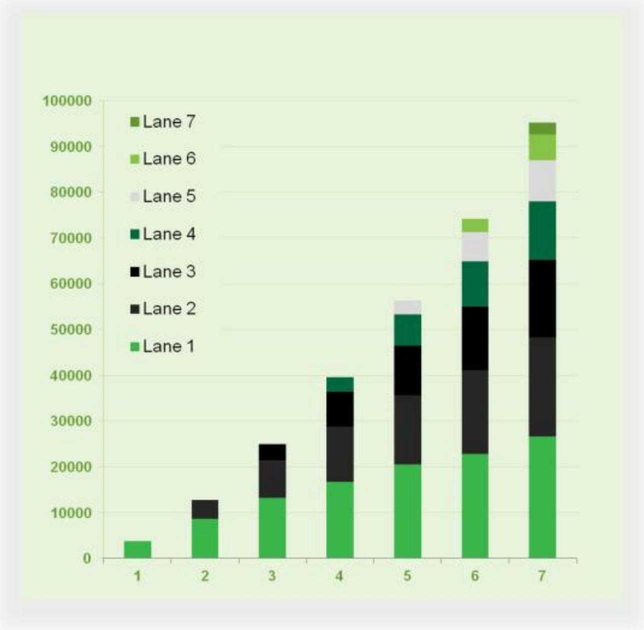
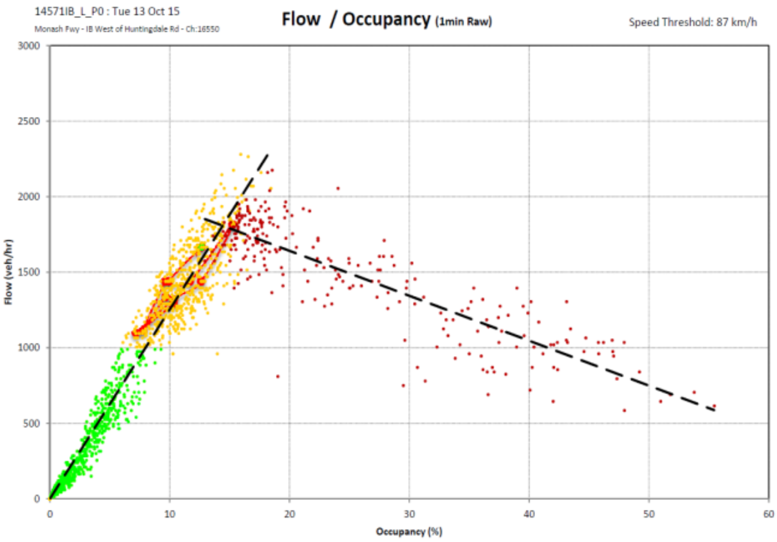


Figure 16 Indicative lane change ratios to service a single point on a motorway in one hour

The traditional fundamental traffic flow relationships no longer seem adequate to explain all the complexities that occur within the traffic stream on multi-lane urban motorways. A single data point in a fundamental diagram usually at best represents one minute periods, refer Figure 17, which also shows the 1 minute trace (red line) of consecutive one minute points (i.e. hysteresis) in the part of the relationship with the highest crash risk i.e.around LOS C. Note the one minute trace shows the points generally jump around rapidly in volume and density, a precursor to high crash risk.



to

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lanes have more lane changes as all the vehicles have to pass through these lanes to get to the faster lanes, and then return through the left lane to exit.

[109] This equates to just one lane change every 2km by every motorists refer (Knoop V. L., 2011) and confirmed by Australian research (Hall M, 2017).

Figure 17 Volume/occupancy plot showing one-minute data

On a four lane motorway operating near capacity each of these one minute periods represents 120-160 vehicles, therefore each of the data points hides a massive amount of detail (i.e. the “lesser fleas”) which is necessary to understand contemporary traffic theory and the majority of urban motorway crashes. Thus vehicles driving closely together can have a multitude of arrangements which can now be observed and studied refer (Figure 18 One-minute flows typically represent 120-160 vehicles), which is equal to each of one-minute data points shown in Figure 17 above.

Figure 18 One-minute flows typically represent 120-160 vehicles

When spatial traffic data is available it is possible to see the crash in detail and the traffic conditions that existed prior to the crash occurring, refer (Figure 19 Speed plot showing perturbation and shockwave before a crash occurred), shown below. The crash event is easily visible in the traffic data, marked with a “ ★”, and showing the preconditions for crashes are already present (i.e. “Event of Exposure”), showing both “Nucleation Events”(i.e. yellow dots) downstream triggering “Shockwaves Events” (i.e. the red/orange triangle). This means that **good drivers can also die or be seriously injured** on our roads whilst aggressive drivers, who often cause these “Chain Reactions”, usually get off “Scott Free”.

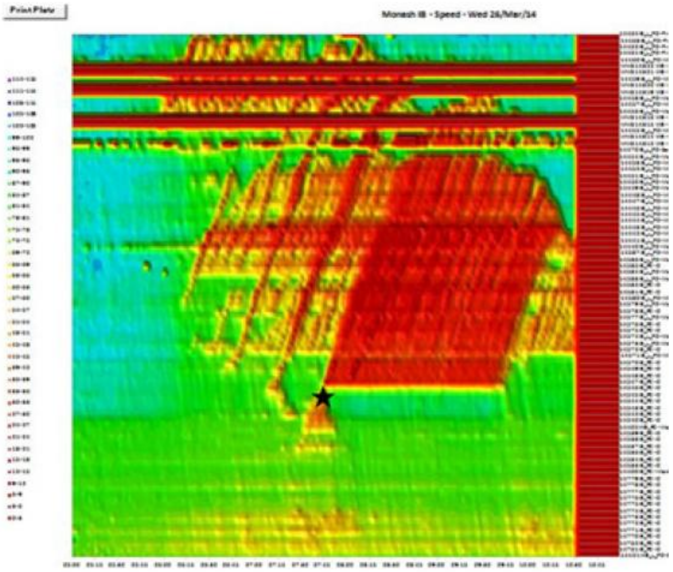


Figure 19 Speed plot showing perturbation and shockwave before a crash occurred

The following Figure 20 coloured in black and white clearly shows a crash event within the forward moving clusters (i.e. lines down the page at a shallow angle), and the backward moving shockwaves (i.e. up the page at a steep angle). A strong or severe forward moving cluster preceded this crash event, shown by the whitish line beside the star (★). The horizontal lines in the figure reveal minor speed variations resulting from other disturbance such as weaving areas, change in grades or cross-section and, friction associated with on and off ramps etc.

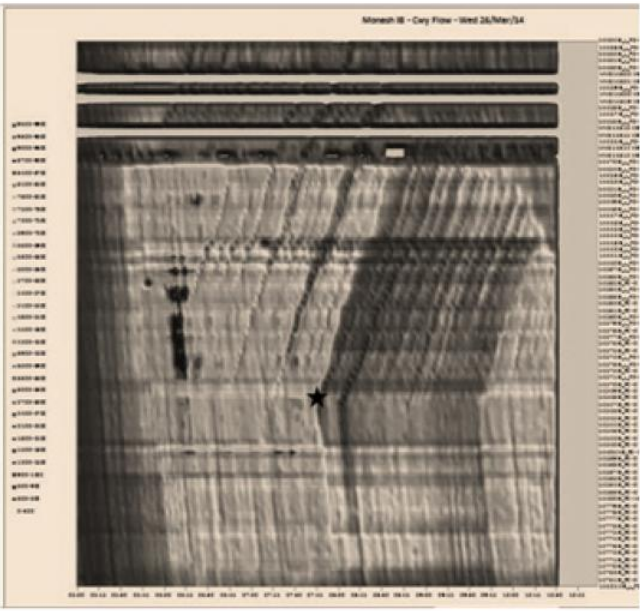


Figure 20 Black and white image showing crash highlighting forward and backward moving waves

Figure 21 highlights clusters of crashes in the certain ranges of lane occupancy (i.e. traffic density) when measured at 5min intervals. “Lane Occupancy” is a metric that can vary every minute of the day and each lane on the motorway can often have very different values. Hence the temporal nature of motorway crash causation in time and space has made it difficult for researchers to fully understand, measure and then develop models for traffic flow and/or crash risk. In Figure 21 there is a high number of FSI crashes in the lane occupancy ranges 5-13%.

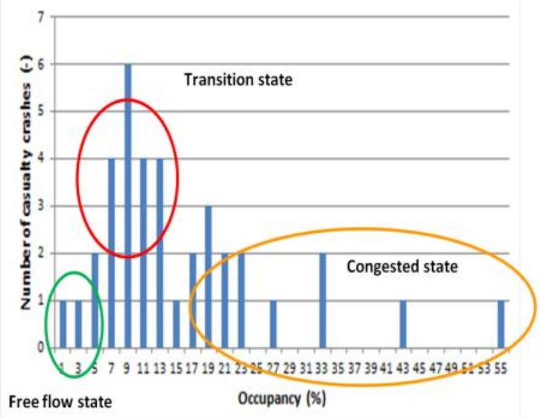
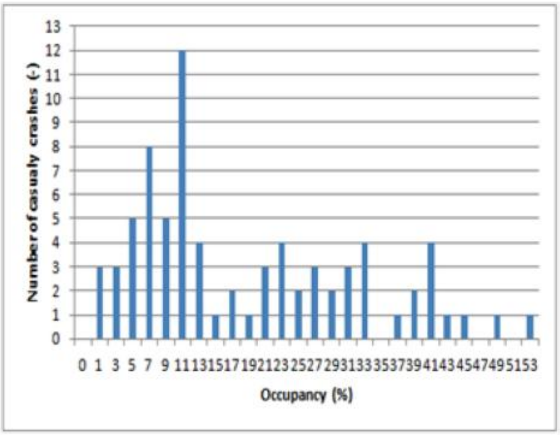
Monash Freeway Inbound FSI crashes	**Monash Freeway Outbound FSI crashes**
	

Figure 21 Relationship btw Lane Occupancy and FSI Crashes - 5min resolution

8.4 Heavy vehicles involvement in crashes

In the Melbourne metropolitan area, approximately 30% of all heavy vehicle crashes occur on the urban motorway network. As the daily exposure of these vehicles is typically around 15%, they are significantly over-represented in crashes and is, therefore, an important area to study the reasons for these crashes. Crashes of such high proportion on motorways did not appear evident from discussions in Europe,[110] however, the Australian urban motorways context in large capital cities, refer Section 1.4, is quite different. Australian capital cities have very high concentrations of commercial vehicles, related to their geographic location in relation to major sea and airports, rail freight terminals and when this is combined with our relatively high levels of affluence driving the demand for increased levels of consumption of goods and services which are mostly delivered by roads as all premises have road access.

It also appears that the Australian heavy vehicle industry in some aspects may not be as well regulated as in Europe, such as their; onboard safety equipment; speed restrictions and driving behaviours (e.g. lane keeping and maintaining safe headways). A cursory glance indicates Australia's has very limited regulations around safety equipment for heavy vehicles when compared to that required by law in European countries with generally better road safety outcomes. Safety equipment such as Electronic Stability Control (ESC), emergency braking, lane departure warning and blind-spot warning should be considered as standard safety kit, for all trucks driving on our roads.

A strong message heard repeatedly during Churchill Fellowship meetings in Sweden, Netherlands and Germany were that the larger heavier vehicles must have the highest vehicles safety standards of any vehicle as they are the most dangerous when involved in crashes. Thus Australia may have a unique situation in relation to the involvement of heavy vehicles including buses, whose crash involvement appears to be rising nationally and, hence there is a need to undertake specific research into understanding this emerging problem to develop solutions along the lines suggested above.

8.5 A changing context for road safety analysis

Given the changing use of motorways in urban capital cities, refer Section 6.1, The Importance of Urban Motorways to the Australian Economy, where it is implied that the context for studying urban motorway casualty crashes in 2017 is quite different to that which would have been concluded from road safety studies just 10 to 20 years ago to, some aspects will be quite different to just 5 years ago, as identified by the changes detailed below:

- Changes to the traffic patterns (i.e. daily volumes, demand patterns, trip purpose, trip origin-destination etc.) all change every minute of the year,
- Changes to vehicle type and vehicle mix (i.e. increasing numbers of both larger and smaller vehicles interacting),
- Changes made by progressively widening and upgrading motorways and carriageways without fully understanding the consequence on road safety and the need for supporting ameliorative treatments at the time of the upgrades. For example, an increased number of lanes disproportionally increases the number of lane changes required for efficient traffic flow. This increases the complexity of the driving task, refer Figure 16 Indicative lane change ratios to service a single point on a motorway.

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[110] May not have been measured in Europe as it appears not to have been investigated in Australia until recently

- Changes to traffic densities which reach critical levels for longer periods every day for much of the daytime hours (i.e. 5 am to 8 pm), and which now occur every day of the week. Temporal traffic density is a key pre-condition for road crashes on all roads, not just urban motorways.

When all these factors combine or align in somewhat indiscriminate combinations, there is strong evidence this creates additional "Events of Exposure" which are the pre-conditions which heighten the crash risk, particularly when traffic density reach values around Level of Service (LOS) C. When these factors are present for more hours each day of the year, as traffic demand continues to grow. Motorways are being stretched beyond their original design limits (i.e. through "sweating the asset") programs or in another language "stressing the asset" for which it appears there are consequences for road safety.

Likewise in rural Australia, it appears that crash rates are rising which should not be surprising as some of the increased crashes may be on major corridors that connect regional areas with urban areas and other roads which have higher volumes for at least some part of the day (i.e. >LOS C). The significant growth in traffic volumes on many major corridors increases the "Events of Exposure" and thus crash risk rises faster than AADT as some events (e.g. "head on" crashes) which grow as a function of the square of the traffic volumes on two way roads (Elvik, Elementary Units of Exposure, 2009). A "run off the road" crash may even be a response to avoiding a "head on" crash which may never be reported.

The definitions of urban and rural have remained static for crash analysis, while the travel in many parts of rural Australia has grown significantly with many rural roads having similar demands as major urban roads did just a few decades ago [111]when they also had higher crash rates. Many rural roads experience moderate to high traffic volumes or congestion for at least some parts of the day refer Section 1.5 (The Problem of Changing Circumstances). Maybe we should create an intermediate category between urban and rural areas, titled "Peri-urban" to focus attention on the higher trafficked roads (i.e. some major rural roads connect to both regional centres and to urban centres) where the crash rates are relatively low but the crash numbers collectively are significant. Due to the higher traffic volumes these roads may have higher crash rates similar to what urban roads experienced 20-30 years ago when they also had higher crash rates. Increased crash risk associated with higher temporal traffic volumes can be explained by contemporary traffic theory as discussed in the next Section9, Understanding Crash Causation from Contemporary Traffic Theory.

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[111] urban crash rates were much higher many years ago when traffic volumes were lower and similar to many rural road are today

9 UNDERSTANDING CRASH CAUSATION FROM CONTEMPORARY TRAFFIC THEORY

The traffic flow theory that has been used extensively for studying motorway flow over the past decade is known as “Contemporary Traffic Flow Theory” which implies that optimal traffic flows are no longer considered to deterministic (i.e. having a fixed or known value e.g. classical traffic theoryt), but rather traffic flows is considered stochastic as traffic flow values can only be determined statistically (i.e. having a 10 or 20% chance of any particular traffic flow outcome occurring in any given time period).

Such understanding reveals new insights into the motorway crash phenomenon, as the conditions that determine high crash risk can now be determined statistically. **It is this understanding and the accompanying traffic science that strongly indicates that crash rates on motorways and heavily utilised sections of divided highways, must continue to rise unless we develop new tools to manage these problems by reducing and/or avoiding the occurrences of the mechanisms involved**.

Before the Churchill Fellowship study, evidence was beginning to emerge that the faster more aggressive drivers can cause disturbances or triggers (i.e. perturbation or shock waves), in the traffic flow which creates certain “Events of Exposure” that can lead to much higher crash risk (i.e. “Chain Reaction” events). The drivers who create many of these problems do not usually crash themselves, hence they often believe they are the better drivers who regularly avoid crashes by their good driving skills with rapid acceleration, braking and fast lane changing maneuvers (i.e. often known as swooping). They may also be the same drivers who regularly complain about slow drivers getting in their way on the road or tend to promote that other people simply can’t drive.

However, vehicles driving safely behind these trigger vehicles, sometimes as many as 8-10 vehicles behind, often find themselves in a circumstance where they have no warning and no reaction time when they are suddenly caught up in an emergency braking maneuver, some of which end up as FSI crashes. Luckily most crashes are avoided as motorists usually find enough time or empty road space to avert the crash. Some drivers have exceptionally good vehicles[112] with good braking and handling performance which is crucial to avoiding many of these crashes or reducing their impacts. These mechanisms can be clearly replicated in traffic flow models as demonstrated by physicist Martin Treiber from the Technical University of Dresden, and are clearly evident in traffic data, and hence must now be considered in future road safety analysis.

As illustrated in Figure 22 from Rune Elvik’s Presentation (Elvik, Elementary Units of Exposure, 2009) it is clearly shown that when any braking sequence is established in the motorway traffic flow it results in the second driver in the traffic flow sequence stopping 33.3 metres and 1.5 seconds after the first driver stops.

Hence in a common “Chain Reaction” sequence involving a string of vehicles the 5th, the 7th or the 10th vehicle in the braking sequence, may not be able to stop safely until a distance of 165m, 233m or 330m respectively has been travelled. The 10th vehicle may be only 250m behind the trigger vehicle and the 10th vehicle may be a heavy vehicle that takes much longer to stop. Hence it not surprising these type of crash events occur and are becoming increasingly common. There seems to be anecdotal increasing numbers of jackknifing articulated truck crashes on motorways which is consistent with this type of emergency braking event

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[112] Refer Section 10 Are Vehicles safe when Faced with an Emergency Stopping Situation?
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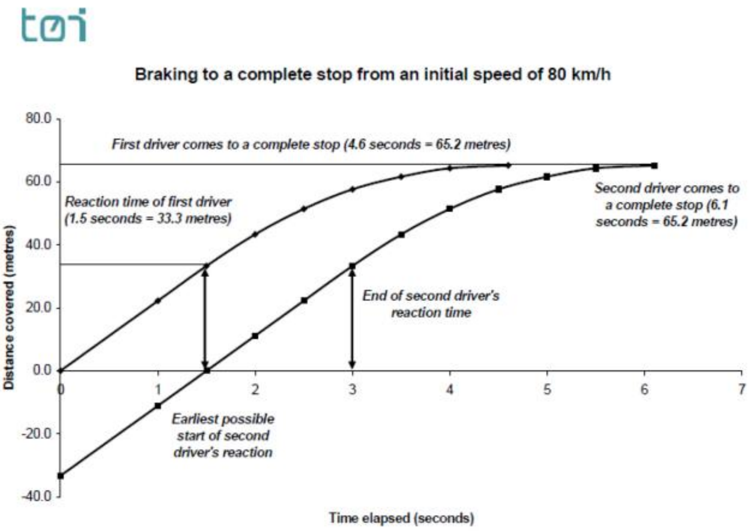

Figure 22 Reaction times and stopping distance of two consecutive vehicles traveling at 80km/h

Thus "Exposure as Events" as described by Rune Elvik above, currently are not measured or estimated in any systematic way, yet they are necessary for understanding the crash risk on urban motorways and divided highways as well as other rural roads with higher traffic volumes. On rural roads traffic engineering principles indicates that motorist's reaction times are much longer than 1.5 - 2 seconds (i.e. 2.5 seconds) as the "mean speeds" are likely to be higher, hence the total stopping distances might be almost double that shown in the above example. As the physical gap between the rear of the leading vehicles and front of the following vehicle, on motorways, are commonly much less than 33m, see graph Figure 23 below, where the mean spacing of light vehicles are shown in orange in the order of 25m, (i.e. shown with the orange dots and orange trend line), are often not adequate for many vehicles to avoid collisions. The green line in the Figure is for average headway distribution of heavy vehicles which is about 8 meters higher than light vehicles but having a much greater stopping distance.

Figure 23 Typical distributions of headways on an urban motorway

Analysis of crashes on motorways and the traffic condition when FSI crashes occur, confirms the traffic theory and thus there are usually critical crash pre-conditions present in the traffic data in the minutes or moments before the FSI crash occurs refer Figure 24 below. Explained below in Section 9.3, Shockwave events are the various forms of shockwaves (backward and forward moving) shown in the figure below.

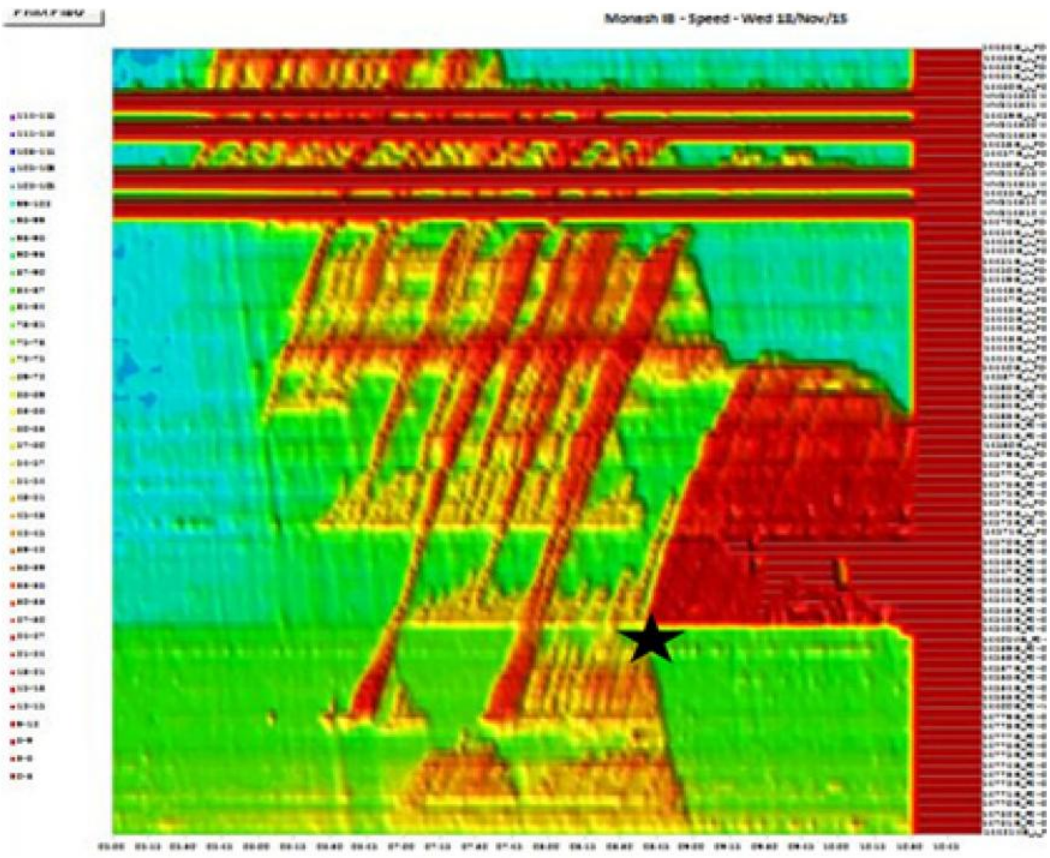

Figure 24 Speed plot showing that the critical pre-conditions before a crash occurs

9.1 New and emerging understanding of traffic theory

A moderate traffic volume for a motorway may be considered to be 40 - 50% of the textbook capacity of 2200veh/ln/h USA HCM flow i.e. 1000 - 1200 veh/ln/h. Such moderate traffic volumes are often considered to be quite low, however, at these flows, the motorway is moving into the operating range where unstable traffic flow conditions begin to emerge rapidly, and when the crash risk begins to rise sharply. However, due to the nonlinear relationship (i.e. parabolic) of the volume/density function, such a traffic volume would generally relate to a density of around LOS C and this same flow can also occur at a higher density at LOS F when flow breakdown has set in. Both density conditions have similar traffic flows but have quite different crash outcomes, with the former being much more dangerous from an injury outcome, and more likely “property damage” crashes in the latter.

Under these moderate LOS C conditions, the driver is unlikely to be aware that that motorway flow could fail suddenly and the need for an emergency braking or maneuvering situation could rapidly arise within seconds. However from a safety perspective especially on urban motorways, traffic volumes in this range are now occurring for much of the daytime hours and the duration of these unsafe traffic conditions is increasing every year, as urban motorways traffic volumes continue to grow. Thus FSI crashes are now occurring throughout much of the daytime hours, refer Figure 5 Typical hourly profile of casualty crashes on a Melbourne urban motorway. The increasing crash risk across much of the day is largely a recent phenomenon in capital cities as the period of the day when these unsafe LOS C conditions occur has been growing by about 15 minutes each year in each peak period, for each of the past 15 to 20 years. On some urban motorways, this now occurs for most of the daytime hours.

These high crash risk mechanisms have been operative for many decades, however, now they occur for much longer periods of the day and hence we are seeing a multiplier effect in the number of crashes. The phenomena have accelerated in recent years as a result of the majority of our urban road network in lane kilometres which was established pre 1980's having only very small additional capacity added. At the same time, populations in urban cities have doubled and travel per capita has continued to increase.

Finally discussions in several meetings identified that over similar periods (i.e. since 1980's) many European cities have continued to invest and developed cross-city higher speed mass transport networks to move people safely around cities and to and from their regional areas and this was indicated as a significant factor for their lower crash numbers compared to Australia.

9.2 Mechanisms involved in "Chain Reactions"

Discussions during the Churchill Fellowship with world-leading traffic physicists Professors Boris Kerner and Martin Treiber were inspirational as their traffic theories aligned closely with what the high-resolution vehicle event data is now revealing. The "Chain Reaction" mechanism mentioned above is also confirmed in traffic theory by Prof B. Kerner University of Duisburg-Essen, Germany.

What was most remarkable were discussions with Prof. B. Kerner that the fundamental traffic flow relationships which all traffic scientists see and use were described as a somewhat simple interpretation of the simple patterns, humans use to explain broad concepts, refer "Narration Bias in Appendix C, Section 1.6. These patterns do not describe what will happen in the next minute in the traffic stream, whether traffic conditions will suddenly fail, suddenly improve or will remain stable.

When data is reported at the 1, 5, or 15-minute resolution, patterns and shapes appear that describe the broad ranges that all the data points fit within. However when we look further into the detail "under the microscope"(i.e. we see the "*little fleas have lesser fleas"),* as at the 20-second or 1-second level of data resolution a lot more detail and complexity emerge. **A "Black Swan"[113] or game-changing event is revealed and this detail explains why urban motorway FSI crash numbers are increasing in moderate to high traffic flows**.

This was explained by B. Kerner as the process of "Nucleation" a term that is usually used to explain in physics or chemistry how ions, atoms, and molecules become arranged in patterns characteristic of a crystalline solid, where additional particles are deposited as crystals grow. Thus within the traffic stream at the elementary level (i.e. vehicles as particles), **we can see almost solid structures form within the traffic flow due to "forward moving" wave**s, refer Figure 20 above, causing random arrangements, resulting in clusters of vehicles that suddenly require drivers to brake harshly.

Instantaneously in time, these events form a somewhat impenetrable almost solid barrier within a carriageway's cross-section involving one or more lanes and sometimes all lanes. This causes many of the vehicles on the motorway to suddenly rapidly de-accelerate, triggering extreme braking events and sometimes triggering a second substantially independent event known as a "Shockwave

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[113] Refer Section 1.8The problem of rare disruptive events

Events", refer Figure 25 below. In this figure after 10am the light vehicles (i.e. cars) have been removed so that motorcycles (shown in blue) and heavy vehicles (shown in yellow) tracking is easier to see.

Such events usually occur without warning for which most drivers get caught unaware yet still avoid crashing, however, one single rare event in many tens of thousands that occur every hour every day, across our cities or across the country will result in a crash.

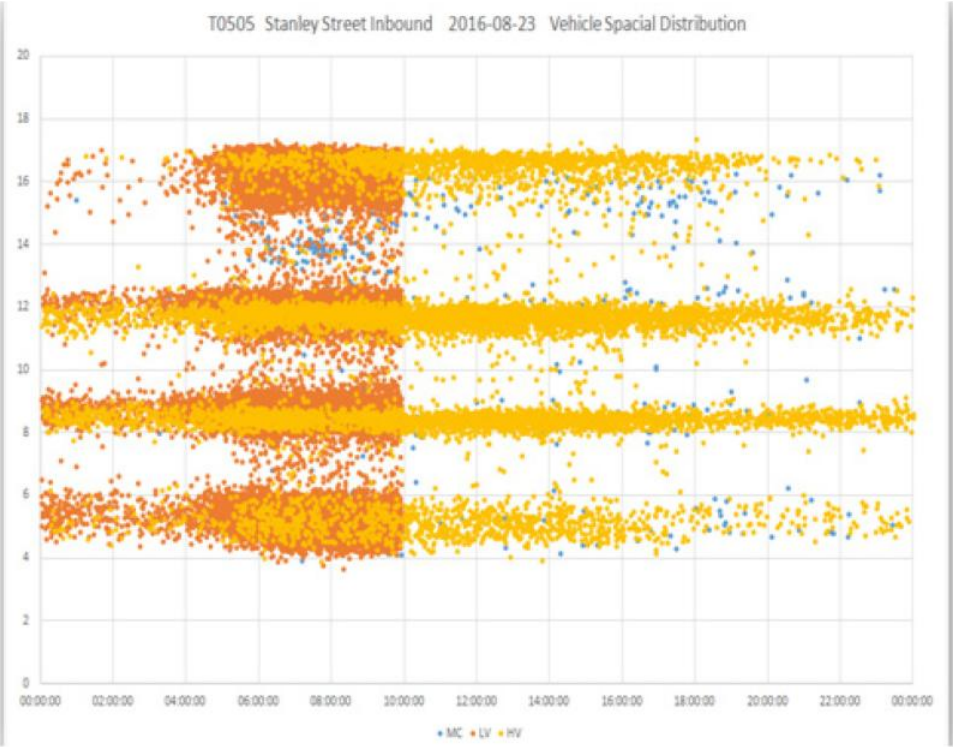

Figure 25 Vehicles event data displaying vehicles as particles revealing the lateral position in lanes

9.3 Shockwave events

As discussed "Nucleation Events" are caused by "**forward moving**" waves travelling downstream with the traffic flow, and are very different to the well documented "Shockwave Events" which travel upstream "**backward moving"** against the direction of traffic flow, refer Figure 26. The "Shockwaves Event" is a consequential mechanism that may or may not form when a "Nucleation Event" occurs, as these events require other factors to be present such as higher upstream traffic densities, creating a dense medium for them to form and promulgate as waves upstream against the flow (Martin Treiber, 2013).

Therefore when moderate to high traffic volumes occur the "Nucleation Events" may at times trigger a second mechanism (i.e. "Shockwave Event), creating a "Chain Reaction" in the traffic flow where vehicles upstream are often involved in crashes. Five commonly seen waveforms are shown below, refer (Figure 26 Different backward moving waveforms common in motorway traffic), with each pattern occurring under discrete traffic conditions with increasing density as presented in a clockwise direction in Figure 26. Usually, these waveforms occur in combinations as the different waveforms along a motorway usually combine, refer Figure 12 Heat plot' from the Monash Freeway (inbound speed profile) which creates extremely chaotic conditions for motorists when separate wave systems combine compounding the crash risk and increasing the complexity of the driving task.

The forward moving waves are clearly shown in (Figure 27 Illustration showing forward and backward moving waves with traffic flows) and these are the main cause of instability and increased crash risk and are often strongest in lower LOS C ranges.

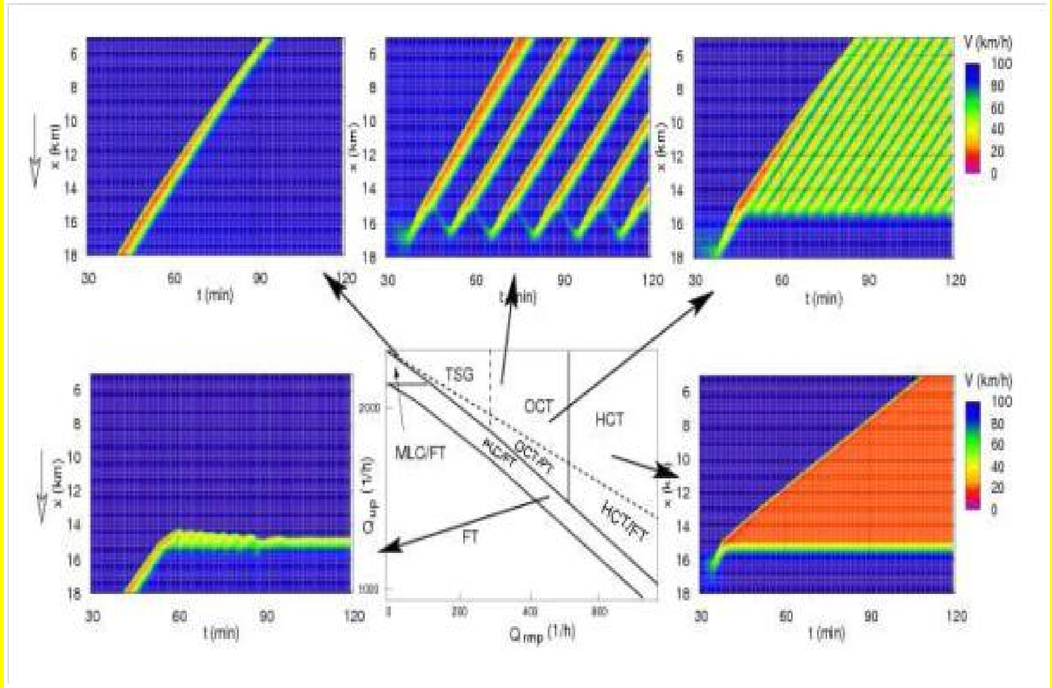

Figure 26 Different backward moving waveforms common in motorway traffic

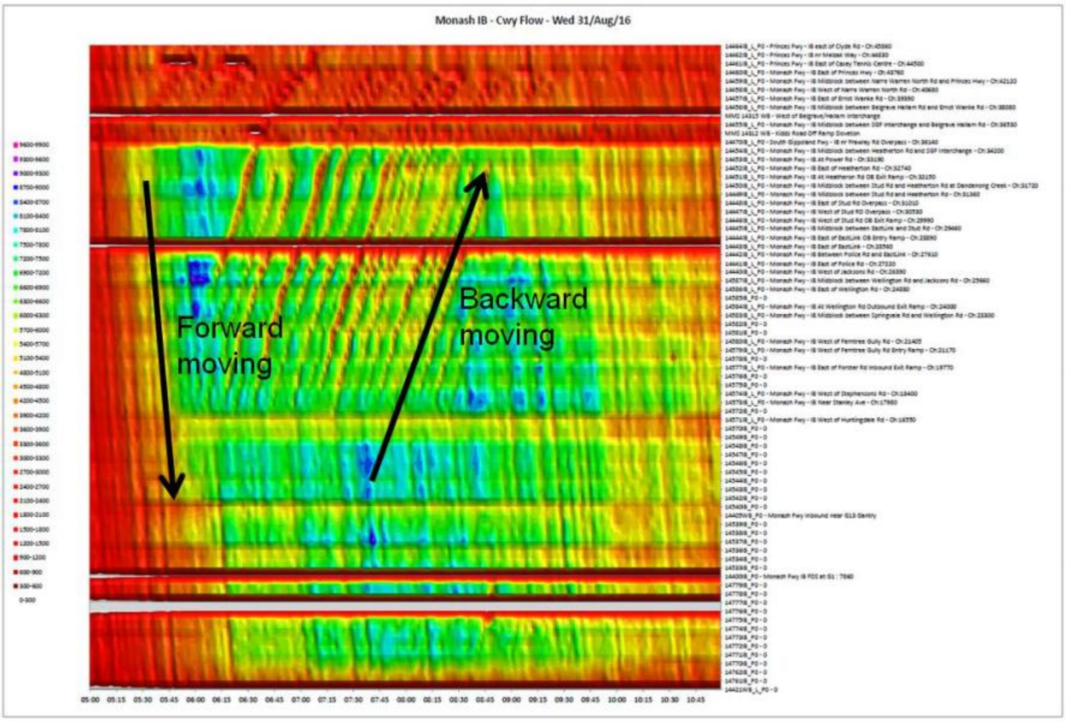

Figure 27 Illustration showing forward and backward moving waves with traffic flows

10 ARE VEHICLES SAFE WHEN FACED WITH AN EMERGENCY STOPPING SITUATION?

10.1 Certain vehicles are more likely to contribute to motorways crashes

The vehicle itself is a key component of the safe system and may be one of the most critical contributory elements of motorway crashes, particularly as it appears that some of the more unstable vehicles are over-represented in urban motorway crashes. As discussed in Section 4.1 certain vehicle groups are overrepresented in crashes on urban motorways. Heavy vehicles light trucks, utilities, larger 4WD vehicles and motorcycle collectively comprise 45% of crashes. When consideration is given to certain "Exposure as Events" and the increasing number of these potentially unstable vehicles now driving on Australia's urban motorways, we should not be surprised to see an increasing number of FSI crashes.

The over-representation of certain vehicles in motorway crashes was the main reason for visiting Teknikens Varld in Sweden who tests vehicle safety performance from the consumer's perspective. This meeting was very insightful as it identified that there is a large variability in the safety performance of vehicles across the entire vehicle fleet, including vehicles of similar classes or sizes. Their vehicle testing in relation to braking and handling maneuvers identified a number of vehicles which are commonly driven on Australian roads which failed the Moose Test",[114] a test required to avoid a suddenly appearing obstacle (i.e. a kangaroo). Such vehicles seemed to have a heightened crash risk.

In particular larger 4WD vehicles are beginning to show up as being over-represented in Australian urban motorway crashes and hence the reason for focusing on the vehicle braking and handling performance in the emergency pre-crash situation occurring regularly on urban motorways or other roads operating in LOS C traffic conditions for at least some period of the day. One of the key messages of this paper is **"crash prevention is better than cure"**, and after visiting Teknikens Varld it seems clear that certain vehicles might be more prone to crashes than others. It may well prove that as vehicles become more autonomous it will be more critical that performance and ability to respond becomes more critical.

Figure 28 Moose Test to avoid a suddenly appearing obstacle standardized in ISO 3888-2

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[114] The evasive manoeuvre test, more commonly known as the "Moose Test" or "Elk Test" is performed to determine how well a certain vehicle evades a suddenly appearing obstacle. This test has been standardized in ISO 3888-2. Forms of the test have been performed in Sweden since the 1970s. The colloquial and internationally better-known name for the test was coined in 1997 by the German newspaper when the Swedish motor magazine Teknikens Varld flipped a Mercedes Benz A Class in a test ostensibly made to measure the car's ability to avoid hitting a moose.

A number of European countries with better road safety outcomes than Australia do not allow new vehicles with less than 4 or 5 NCAP Stars to be registered and access the public road network. Yet vehicles with less than 4 Stars are routinely allowed to be sold and driven on Australia's roads. It would appear from this study that both vehicle pre-crash safety and vehicle handling performance may be the most critical areas in the future to improve road safety outcomes and the practices associated with the "Safe System" approach. It seems logical to start at the source of the problem with the vehicle as the most critical component of the safe system (i.e. the thing that conveys people and goods and which crashes into things). Thus maybe Australia should be following some European countries lead by only allowing 4 or 5 NCAP stars rated vehicles to be purchased and driven on Australia's roads, and in addition, ensuring that all new vehicles have adequate braking maneuverability to handle expected everyday traffic conditions (i.e. "Nucleation Events" and "Shockwave Events").

10.2 Testing vehicles braking, maneuverability, and stability

As discussed there is strong evidence in Australia that the larger trucks, light trucks, utility, larger 4WD vehicles, and motorcycles are revealing themselves to be unstable when placed under emergency braking or steering conditions, which is often necessary to avoid a motorway crash or a crash at any location, particularly on rural Australian roads (i.e. avoiding kangaroos). At times these vehicles travel on greasy road surfaces after long dry periods following light rain or heavy overnight dew without adequate payloads (i.e. less than a one-ton payload some commercial vehicles can become quite unstable in greasy conditions), particularly utility vehicles. As the mechanisms involved in a large number of motorway crashes are now understood, braking efficiency and maneuverability under emergency braking situations are considered vital to avoid crashes particularly as drivers often receive little or no warning and have little or no reaction time.

Stability problems were first noticed many years ago in a Mercedes Benz which first resulted in the maneuverability tests being developed. There is now an important vehicle safety test known as the "Moose" or "Elk" tests for European vehicles where a vehicle must be able to pass a maneuvering test, a test that has been standardized in ISO 3888-2. Currently these test and their results are not widely acknowledged or promoted in Australia as they are carried out by overseas organisations and only one vehicle in a range of model variants are usually tested which appears to be a major shortcoming of this test.

Even though vehicles standards exist internationally, in light of the number of crashes which occur on Australian roads we must consider these or similar standards for Australian vehicles and at least advise consumers of the vehicles relative performance and, work towards higher standards for our Australian vehicles as it appear some current standard may no longer be adequate. It was suggested following discussions with Teknikens Varld that such tests should apply to all new vehicles including all model variants and modified vehicles (i.e. those fitted with aftermarket products), with non standard wheels, tyres and suspensions before they are allowed to drive on Australian roads at highway speeds.

Consumer testing of thousands of new vehicles is undertaken by Teknikens Varld, Sweden and revealed that some common and popular Australian 4WD vehicles perform very poorly in the "Moose Test". Testing reveals that these vehicles rollover at speeds as low as 60km/h or regularly deflated their tyres (i.e. the tyre seal with rim is cracked during the test) when the moose test was performed. It appears that amongst 4WD enthusiasts in Australia these issues are reasonably well known but this information does not seem to have filtered up to policy makers and legislators. Teknikens Varld indicated some of these vehicles should probably not be allowed to be driven on the road as they are quite dangerous and there has been known problems with some vehicles for more than a decade.

Independent stability and maneuvering testing does not seem to be carried out in Australia and therefore poor braking, handling during ESC operation, create a critical safety issue under certain conditions (i.e. a critical pre-condition for many motorway or highway crashes).

Poor “Moose Test” results have occurred on a broad range of vehicles so this issue is not just limited to 4WD vehicles. Some European 4WD vehicles that are known to be problematic have been subsequently redesigned (2017) for the European market, however based on the Tekniken Varld report it appears that similar Australian vehicles are not being fixed as they come from a different factory for “right-hand drive” vehicles. It is unclear whether anyone in the Australian vehicle regulation area reviews these European tests and then follows these matters up here The well publicised internationally Toyota Hilux roll over problem has now been fixed in Europe for left-hand drive models, however, according to the Teknikens Varld’s report, these modified vehicles are unlikely to come to Australia as there seems to be no one actively lobbying on behalf of motorists and consumers. We need to confirm whether this is the case in Australia and identify which peak body is responsible monitoring the many vehicles identified as being problematic in Europe, in particular, Sweden.

Figure 29 Toyota Hilux initially failed the "Moose Test” - then redesign and modified in 2017

Wheels, tyres, brakes and suspensions combinations working in conjunction with ESC are crucial for safety, yet it appears that Australia does not currently perform independent testing in this important area rather than relying on the initial international certification. What data does the road safety industry collect in Australia on this matter? Australia should probably go a step further and rate all vehicles on their handling performance in emergency braking conditions and in light of the motorway crash problem, develop standards proportionate to the problem and, preferably include separate braking[115] and handling performance tests in the ANCAP star rating score. Before Australia introduced the ANCAP, not all vehicles coming to the country were of the same safety standard as the ones going to Europe or used in Japan. This again may be the case as right-hand-drive vehicles often come from different factories.

10.2.1 Concern over variations between models

Testing at Teknikens Varld showed major differences in the braking and handling performance of the same vehicle model between different configurations of the model (i.e. engine size, cabin (single/twin) and flat tray/utility/enclosed canopy type configurations), as well as the way consumers place passengers in their vehicles and carry loads in the different models. Consumers are usually not aware of the implication of minor redistribution of weight can have on braking performance and handing in conjunction with ESC operation in an emergency situation. It seems that not all model variants are tested by the manufacturers when their new models are tested and approved. Thus the diverse range of possible vehicle variants including common aftermarket fitments (e.g. canopies), are not tested in the initial manufacturer's vehicle approval process at the time of vehicle's original test certification. Such tests should be thus considered as an extension of the Australian NCAP vehicle testing program.

Tekniken Varld mentioned one bad example where an electric vehicle which had the battery pack installed near the rear “backrest” did not perform the “Moose Test” well as the weight distribution and vehicle configuration, wheel combinations and ESC systems were not well balanced for vehicle handling.

Discussions implied as well as the body variants mentioned above the various loading provided by the consumer (i.e. driver only or with a number of passengers) and, with various payloads and weight distribution, yet the ESC was often standardised and hence not able to provide ideal control in all the combinations and situations when the vehicles are driven on the road. This became obvious during Tekniken Varld’s testing that more passengers in vehicles and more luggage in different loading configurations resulted in a wide range of outcomes from the ESC system, some of which were often considered dangerous or outside the range a consumer would expect when Teknikens Varld had to brake or swerve suddenly. The tests often showed that under some loadings and vehicle configurations, the vehicle behaviour would have a much higher crash risk.

10.3 Does the vehicle aftermarket industry need a review?

In simple terms, the method of operation of Emergency Stability Control (ESC) is to first reduce speed and, second to point vehicle in the right direction. According to Teknikens Värld test driver, Linus Pröjtz, the Porsche Macan performed “strangely” during the “Moose Test” (Porshe), as the left front wheel locked up during the test. This meant that rather than turning the vehicle to get back into the correct lane after the evasive maneuver, the Macan bounced in the opposite direction increasing the likelihood of entering the lane of on-coming traffic. Such a manoeuvre risks the

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[115] i.e stopping distance

chance of a head-on collision with another vehicle in real life conditions. Fearing that the test vehicle might have been faulty, they again performed the test again on a different vehicle of the same model and the result was “equally bad”.

Yet vehicles with highly modified braking and suspension are allowed to routinely drive on our roads. Therefore if a leading vehicle manufacturer has some difficulty always achieving the correct performance out of their vehicle in emergency braking and steering, the question must be asked how well will aftermarket equipment work without appropriate engineering and testing.

One person in my office indicated that their father had their 4WD modified with off-road suspension suitable for travel around Australia on outback roads. They had the suspension modified which raised the center of gravity of the vehicle. Long story short, the vehicle rolled over injuring his parents. The consequences of this were not understood by the driver as these vehicles become dangerous at relatively low highway speeds, (i.e. 60km/h), refer Figure 29 showing a non-modified vehicle rolling over at 60km/h.

In Australia, many vehicles are routinely modified by consumers with aftermarket products that usually have not been tested to the same level of scrutiny or performance that a vehicle manufacturer is required to undertake. Tekniken Varld tests showed changing just the wheels and tyres for off-road driving meant that often ESC and brake combinations were no longer suitable for driving at highway speeds and will underperform during emergency steering or braking situations (e.g. stopping distance may increase 10-20%).

Tekniken Varld highlighted that all vehicles needed to be “built from the ground up”. They meant that the combinations of wheels, tyres, brakes, suspension, steering, and ESC were critical to the vehicles overall safety outcome. Exactly what happens when these components are modified with aftermarket products is a complex matter. Tekniken Varld advised that just changing one simple component such as the tyre brand or brake pad, significantly changes how a vehicle will perform in an emergency braking or steering maneuver which usually occurs in the moments before a crash. With lower performance brake pads or different tyres the stopping distance may be increased by 10-20 metres which could be the difference between crash avoidance or a serious injury.

The large aftermarket industry in Australia provides various wheel types (i.e. sizes and widths, and tyres brands) including tread patterns, profiles and tyre compounds, suspension systems and components. Modifications are made to braking systems and the use of various brake pad materials with different braking performance with little or no regulated method for ensuring consistent standards for vehicles safety performance. Therefore new regulations may be required to further reduce the number of crashes on our roads. Maybe these modifications do meet an existing replacement part standards, however, these many need to reviewed and strengthening, particularly in light of ESC systems that may not have been anticipated when these standards were originally developed and may not have, taken full account of the current safety crash risk phenomenon. The consumer at least needs to be made fully aware of these issues as is the case through Teknikens Varld magazines and online technical articles.

Does Australia have independent vehicle testers in Australia who can actually test all the complex issues associated with these matters? Are these modified vehicle configurations safe both on the outback road and also when driven at highway speeds? Wheel and suspension combinations which might work exceptionally well in off-road conditions at slower speeds may not perform safely at highway speeds. This matter should no longer be ignored and thus we must explore all these avenues to ensure that vehicles are fit for purpose, if we are to lower the road toll further. At the very least a detailed technical analysis of all “written off” vehicles needs to be undertaken to confirm whether vehicle modifications including suspensions, wheels, tyres and brakes are contributing to the crash problem.

Discussions with a motor mechanic in the UK who had worked in the vehicles repair industry for over 40 years revealed that he has always refused to service modified vehicles primarily due to the fact they were unsafe and dangerous. Yet Australia, in particular, has allowed vehicle modifications to occur routinely often without adequate audit, suitable tests and common standards overseen by the road safety industry. A vehicle engineering assessment of all vehicle modifications needs to ensure that there is a suitable test for how a vehicle handles under a controlled emergency braking and maneuvering situations (i.e. "Moose Test") and whether they are compatible with ESC systems. Current ADR standards although they may be based on international standards, contain emergency braking tests which may no longer be adequate for many of the circumstances encountered on the modern road network (i.e. "Nucleation Events" and "Shockwave Events")[116, 117] which must now be taken into account in the way we understand road safety (i.e. the "Black Swan" event).

10.4 Tyres deflating during testing may be reflecting a bigger problem

The fact that tyres can deflate before a crash occurs is not something that a police report would necessarily record or something the police could possibly know. This is also something the driver of a vehicle may not be aware of, as crashes occur within split seconds and the tyre may deflate before the vehicle actually crashes (i.e. sometime in between when the emergency evasive action is taken and the crash event). Thus the contribution of tyres deflating in the moments before the crash is often not identified or considered as a possible crash contributor. We therefore need to include in police records whether the tyres were deflated as we must no longer assume a flat tyre was caused by the crash impact itself. The deflated tyre, particularly the outside front tyres was common when doing the "Moose Test" to a range of vehicles models tested at speeds up to 70km/h, including occurring on some cars, as it is believed that sometimes the rims flex under steering stress which deflates the tubeless tyre. One common Australian 4WD vehicle continued to blow tyres on 3 different vehicles when performing the "moose Test".

There is also some antidotal evidence from dash cam (camera) data that tyre deflation (i.e. blowouts), may be a more common cause of crashes than currently realised. Hence tyre blowouts being the possible cause of many crashes is a field that appears to be under-investigated as a cause and thus this needs to be coded clearly in crash reports as a possible crash cause. Due to improvements in tyre technology over the past 20-30 years, a tyre blowout is a unique type of crash which usually takes the driver totally by surprise as blowouts are rare events. The driver's reaction times are likely to be much slower and the correct intervention by the driver might not occur, particularly in rural driving when reactions times are much longer. This is another "Event as Exposure" that needs to be considered and investigated as crash events are rare (i.e. one fatality in 192,000,000 kilometres travelled). What is the equivalent chance of a tyre blow out? Mostly likely once every few minutes on our Australian roads or many times each days.

Possibly we need to survey drivers and monitor the proportion of flat tyre repairs in rural areas versus urban areas to get a feel of the size of this problem and how many such events occurred each week whilst a vehicle is driving at highway speeds or on our rural road. Further improvements in road safety will only come about by chasing these "One Percenters". Many modern vehicles have their tyre pressures monitored so it may be possible that the vehicles computer system would time

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[116] e.g. Vehicle Standard (Australian Design Rule 31/03 – Brake Systems for Passenger Cars)

[117] e.g. Vehicle Standard (Australian Design Rule 35/04 – Commercial Vehicle Brake Systems) 2013

stamp the tyre pressures before the moment of impact. Tyre blowouts may have a more significant level of crash involvement than we currently realise. Therefore we must collect data somehow from the tyre repair centres and the drivers who come in for tyre repairs to quantify the significances of this problem including adding this detail to police crash reports.

The author of this report has had a tyre blowout in a brand new car at night time in the right-hand lane of a rural divided highway, as a result of a small defect in the road pavement. Such events are quite surprising and require considerable alertness and skill to keep the vehicle stable and not to overreact. It appears low profile tyres may be more prone to damage from poor pavement maintenance than other tyres.[118] Has this problem been studied or investigated as it appears low profile tyres are known in the industry for the ease in which they puncture on poorly maintained roads? We need to establish the linkage between road safety and adequacy of maintenance levels of road network and the standards of vehicles that we allow to use the road system, now and in the future. It was suggested although somewhat sarcastically that Australians have moved towards purchasing larger 4Wd vehicles in proportion to the decrease in road maintenance as many roads remain rough and bouncy even after resurfacing and thus stronger vehicle suspensions and tyres are now needed.

10.5 Crash avoidance strategies must be a priority

Avoidance of all crashes needs to be set as the highest priority by road safety professionals. As discussed in Section 17.4.1 (The Luck of the last 150mm) below, the difference between a minor injury and a serious injury may only be a 150 mm difference as to which part of the body is impacted (i.e. the shoulder, brain or another vital organ). When any crash occurs, no matter what speed the vehicle is travelling, or on which road type, or what location, we cannot guarantee the crash outcome. Research in Germany showed some higher speed crashes result in little or no injuries while some other low speed crashes can result in fatalities[119]. Thus we need to focus on understanding the pre-crash vehicle braking and maneuvering performance as a key factor in crash avoidance. Evidence shows many potential motorway crashes are avoided often by only a matter of centimetres.

Reviewing many road safety strategies that vehicles braking and handling performance in emergency stopping situations has been overlooked, as programs focused more effort on what happens during the impact event. Hence consumers have not been made aware that their vehicle may not handle well in an emergency braking or swerve maneuvers required to avoid most crashes. Therefore more emphasis and resources must be placed on the other three safe system pillars being safe vehicles, safe speeds, and safe drivers. Also road maintenance interventions are required for safe roads to support the modern vehicles fleet.

10.6 Are SUV Safer Vehicles

Research by the insurance industry in Sweden is suggesting that SUV type vehicles are not necessarily safer vehicles as marketed or as believed by consumers. In particular, the larger 4WD vehicle whilst they may be safer on outback roads some have significant vehicle handling concerns when travelling on highways at highway speeds which becomes evident when emergency braking or

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[118] Low profile tyres maybe more susceptible to punctures on poorly maintained motorway and highway pavements where vehicles travel at speed and hence this issue needs to be researched by discussions with tyre repair centres.

[119] German research e.g. GIDAS showed that often crash reporting was selective in its findings by reporting (filtering) only crashes of a particular injury level or outcome rather that studying the complete distribution of all crash outcomes. This often lead to biased policies, strategies and solutions.

swerving is required to avoid an animal or collision with another vehicle, particularly at speeds above 70km/h.

Sweden insurance companies have identified an apparent AWD and 4WD safety issue –refer (M. Rizzi, 2016). It was suggested that these vehicles may be driven harder, as motorists have purchased them on the premise they are safer at handing in adverse or inclement conditions. Due to their physical appearance and design, they give the impression they handle and grip well and are safe to drive, but only up to the point where the tyres lose their grip. They then crash harder as the drivers appear to have taken more risks.

However, on the contrary, some Australian research tends to indicate AWD and 4WD do not seem to be problematic, however, has enough research been done particularly when context changes? A prominent Australian reference is a report funded by RACV and undertaken by MUARC (M.D. Keall, 2006) which indicates that 4WD drive vehicles studied in Australia do not seem to be a major problem. However, times have changed significantly (i.e. time-trend bias), since this work was published in 2006 and which investigated the Australian 4WD vehicle fleet between 1987 and 2003.[120] Since then there has been a very significant rise in 4WD sales in Australia as well as significant improvements in their crashworthiness including ANCAP ratings and ESC was made mandatory in January 2013.

Since 2003, Australia has seen a rapid increase in the numbers of larger 4WD and changes to where and how these vehicles are being driven. They are now being driven commonly as family cars on urban arterial roads and motorways, which means these older studies[121] are no longer appropriate for understanding today's changing the context of road crashes. VicRoads R&L systems show that 4WD are over-represented in the "written off" vehicle registry for the category "written off by crashes" as well as being over-represented in crashes on urban motorways.

Thus safety issues relating to 4WD vehicles today appear contrary to the more recent Australian research that shows that 4WD/SUV vehicles are not necessarily more dangerous. While these studies are important, they also highlight the need that such studies need to be continually reviewed and updated as transport in Australia is continuously evolving and vehicle types, size, and the mix is changing quite rapidly and thus road safety programs and solutions must also adapt in response to relatively rapid changes in contexts.

10.6.1 Research can often become quickly outdated

Since the above report by MUARC was published in 2006 expectations for road safety have increased and what may have been a good road safety outcome prior to 2006 for the period dating back to 1987, is no longer considered acceptable today. Road safety expectations are much higher today as the road toll has been reduced considerably since the period of the data used in this study. For example in 1995 the midpoint of the data collected for this study more than 2000 people died on our Australian Roads compared to around 1300 today.

It is also clear that ESC has made a big difference in reductions in 4WD crash outcomes, however rollover crashes still seem to be relatively high amongst 4WD vehicles. Urban motorway crash involvement with 4WD vehicles including potentially multi-vehicles crashes, remains a problem. Therefore a more targeted effort is required to reduce the numbers of serious crashes caused by these types of vehicles on motorways.

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[120] The mean of the crash data period is 1995 some 22 years ago

[121] in this case 2006 does not appear that old, however the data it referred to is very old

We now see a greater mix of larger vehicles mixing with smaller vehicles on our roads, which is likely to increase further if electric vehicles become more common as is the current situation in Europe. Research shows when larger vehicles hit smaller vehicles, the smaller vehicles even if they have a five Star ANCAP rating come off quite poorly (e.g. a simple case of physics). This is an issue which consumers need to be made fully aware of so that they understand their vulnerability, particularly when driving in mixed traffic on heavily trafficked motorways with higher speeds.

In much of Europe, the larger 4WD market is currently relatively small. Therefore issues associated with larger 4WD is primarily a matter for Australia (and maybe also the USA) and thus Australia needs to invest its own research time and effort to understand and develop solutions to these problems. Concern was expressed in Sweden (VTI) that whilst these vehicles numbers on average were still small, there was a growing market for the larger 4WD vehicles and, hence it was seen as a potential emerging problem for them as well. My observations were that the larger 4WD vehicles and larger motor vehicles generally seemed to be more prevalent in the UK than in other parts of Europe and therefore Australia could possibly look at their research and/or crash data as well.

Since the 2006 study mentioned above, the vehicle fleet as a whole has generally become much safer and hence no matter how good the research was at the time, due to the “time series” bias, many reports should no longer be widely used as references without qualification or until they have been reviewed and updated. Consideration should be given for major institutions that publish research reports to have an obligation to review their own reports for currency and either update them or make them accessible only because the methodology used in the research might still be robust and useful to other subsequent researchers. They may need to be marked with suitable warning messages about their currency, highlighting context changes for subsequent readers who are generally unaware of the “time series” bias. It became clear by reading research that many agencies often still use assumptions from old research and reports, often dated 20 or more years ago, including using crash reduction factors for interventions which no longer have currency.

10.7 Lifting the standards of vehicles using our roads

Ralph Nader wrote a book on the vehicle industry in the 1980s titled “Unsafe at any Speed”, refer Figure 52. While a lot has change has transpired since then in regards to vehicle design and safety, it is considered timely we refocus some of our road safety research back to the source of the problem – the vehicle – by statistically measuring each individual vehicle’s actual on-road safety performance over the many years they are driven on our roads. It is acknowledge this is done to a very small degree by ANCAP but this potentially falls short of what could be done in this area.

We can no longer assume all vehicles using the road perform at the same or similar levels in terms of their safety, braking and handling performance. Until we change our approach the consumer will continue to be unaware of problematic vehicles. In Norway and Sweden for example only vehicles with the higher star ratings i.e. 4 and 5 stars, are allowed to be registered. Other countries including Australia report on how good or bad vehicle performs over their life, however, this discussion is about taking our current used vehicle safety ratings to a new level in Australia. Australia needs to proactively eliminate unsafe vehicles from our roads and we should not see this problem as being too difficult. We must identify problematic vehicles including using evidence from overseas and be prepared to name the problems and work with the vehicle industry to resolve them. This has already been shown to be the case with the recall of defective Takata airbags in many Australian vehicles which maybe just the tip of the iceberg.

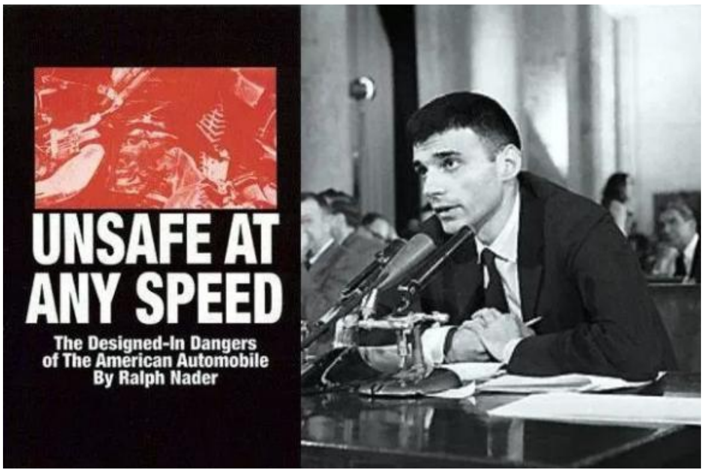


Figure 30 Ralph Nader’s “Unsafe at any Speed” warning on vehicle safety performance

It would appear from the testing undertaken by Tekniken Varld discussed above that vehicle manufacturers often don’t do adequate testing between different brake systems, engine sizes, body configurations, wheel sizes and tyre combinations across all the model variants. One example quoted was from the popular Jeep Cherokee refer Figure 31, which released a particular model variant with the increased braking power which was not matched to ESC system. **Consequently its handling was very poor when doing the “Moose Test”. Tekniken Varld used the language ” *that these vehicles did not understand the road”*.**

Figure 31 Tekniken Varld Jeep Cherokee “Moose Test” at 63.5km/h in 2012

The key message, repeated by Tekniken Varld was something as simple as the wrong tyres can compromise handling and can add 10m to the stopping distance. Tyre grip is important and simply changing tyres (i.e. brand or tread patterns), can make 10 seconds driving time difference on their 80-second test track which was indicative of vehicles safety performance in emergency braking and maneuvering events. Since such a minor change can have such a big effect on a vehicle's performance we can no longer avoid talking and doing something about these problems. It is noted that tyres will perform quite differently on different pavement surfaces and what works well on dry pavements may not perform well on damp or wet pavements.

A practical example for the author was when driving a basic “low end” of the market hire car in England whilst on the Churchill Scholarship, which was a very new vehicle, highlighted how poorly the "low end" of the market vehicles actually perform. I drove several thousand kilometres and felt that I had to concentrate much more on my driving which was tiring as the vehicle seemed to float and wander whenever there was a small irregularity in the pavement surface. Was this particular vehicle's performance an aberration or was this normal for this make and model? It appears that we may be allowing very basic vehicles with "low end" handling and braking performance on our roads. We therefore may need to revisit existing vehicles braking and handling performance standard, or at least measure and understand their impact on road safety outcomes, particularly in light of new understanding that "Nucleation Events" wherever they occur, require driver to avoid crashes with minimal or no reaction time and which is beyond the capability of many vehicles on the road as evidenced by crash records. Hence more weighting or emphasis needs to be placed on crash avoidance capability of vehicles and/or at least educating motorists that their new vehicle is a low end performer.

10.7.1 Vehicle manufacturers may have different priorities

Teknikens Varld indicated vehicle manufacturers seem to be driven by different objectives to Road Authorities and/or MOT's, and hence vehicles are designed typically in the following order of priority:

- 1st minimise rolling resistance (lower fuel consumption figures means larger diameter wheels also noticeable on electric vehicles
- 2nd lower noise for driver comfort to increase sales,
- 3rd braking and vehicle emergency handling as the last priority

Teknikens Varld indicated it is difficult when designing a vehicle to get all the above criteria in balance as braking generally requires a different tyre configuration and compound, that may make more noise and add more rolling friction and thus increase fuel economy. The European Union have developed tyre rating systems for speed and noise but these do not cover the more important braking performance of tyres. It appears that all vehicles generally and particularly some popular electric vehicles are going for larger diameter wheels and narrower tyre width to minimise rolling resistance, however, this does not minimise braking distance or improve vehicle handling and thus affects the vehicles crash risk.

10.7.2 Is safety linked to vehicle exposure and /or vehicle age?

It was suggested many times that Roads Safety can be linked to the age of vehicle and MOT's need to measure annual vehicle kilometres of travel (VkT) from odometer readings. Sweden has been able to show that new cars do the higher VkT and the older cars tend to be second cars and are driven less. Teknikens Varld suggested that older vehicles tend to travel less on average, however their involvement in crashes seems to be much higher when their exposure actual is taken into account. This may be the case on urban motorways in Australia where the average age of vehicles involved is crashes is 9-10 years i.e. the average of the vehicle fleet, however antidotal observation evidence suggests that the vehicles that use the motorways regularly on average might be lower than average vehicle involved in a crash. Do we know in Australia the answers to these types of questions?

Collecting this data as Sweden does (trafa.se, 2013) will highlight any skew in crash statistics and whether older vehicles are over represented in casualty crashes based on their exposure and or condition i.e. vehicles travelled age based on its actual physical condition and distance travelled.

Vehicle age is not an indicator of vehicle condition in relation to handling and braking, so on its own is not the right indicator. Some 10 year old vehicles have done 50,000 km whilst some have done 500,000 km where it may be expected on average the one with the greater usage might show more signs of wear, tear and fatigue in critical brakes and suspension components.

If we don't measure exposure we cannot expect to fully understand the road safety implications of safer and newer vehicles, or the effects of wear and tear on younger vehicles which have traveled many kilometres above average, as many younger vehicles used commercially can travel 80,000 – 100,000 kilometres per year. The odometer reading must also be captured in crash reports to see whether wear and tear of travel over time are linked to crashes rather than just the physical age of a vehicle. It became clear that MOT's need to collect very accurate data on kilometres travelled for each registered vehicle each year. This is done in Sweden through the MOT annual registration renewal process.

Australia primarily uses VkT estimates based on fuel consumption which forms a surrogate measure of travel exposure. This is not considered appropriate or detailed enough for road safety reporting or crash analysis as the systematic error in these estimates is likely to be higher or lower than the benefits reported, as the crash rates determined from such data might be higher or lower. If Australia wants to reduce crashes further we must know the travel exposure and physical condition of all vehicle classes and individual vehicles involved in crashes to find out how this might be contributing to crash rates and crash numbers.

10.7.3 How do vehicles perform over their life?

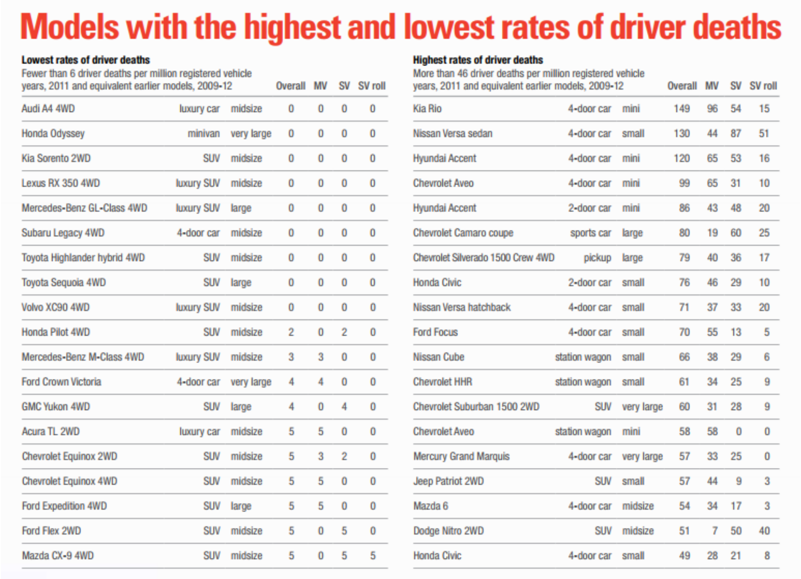
Vehicles ANCAP star ratings for crash worthiness and onboard safety equipment are no longer enough to ensure best possible road safety outcomes. Vehicle braking and handling capability that occurs immediately before a crash needs to be considered as part of future vehicle testing regimes in Australia.

Discussions highlighted the need to study vehicles actual safety performance by make and model after it has been sold, and not base our judgments only on new vehicle star rating performance alone. We must know how vehicles actually perform over their lifetime and what goes wrong during their normal operating life i.e. reduction over time in braking, suspension and steering performance. It is possible some vehicles will perform badly and should be recalled and consumers need to be advised of relative performance of all makes and models.

One way to compare the relative safety of vehicles is to look at driver death rates for each vehicle model. From time to time, the USA Insurance Institute for Highway Safety (IIHS) researchers measures the rate at which drivers of individual models are killed in crashes refer Figure 54 USA Insurance Institute for Highway Safety (IIHS) death rate (driver)

To increase the exposure and thereby improve the accuracy of the calculations, IIHS results are included for the previous three model years if the vehicle wasn't substantially redesigned during that time. These calculations take into account only deaths of drivers, not passengers, since every vehicle that crashes has a driver, but not every vehicle has passengers. See graph below of the USA Insurance Institute for Highway Safety (IIHS) death rate (driver only) for small 4 door cars and note the overall death rates and involvement in multi-vehicle, single vehicle and rollover crashes, refer to Figure 55, for comparisons across of all vehicles noting the wide range of safety outcomes.

Figure 32 USA Insurance Institute for Highway Safety (IIHS) death rate (driver)



Models with the highest and lowest rates of driver deaths

Lowest rates of driver deaths

Fewer than 6 driver deaths per million registered vehicle years, 2011 and equivalent earlier models, 2009-12

			Overall	MV	SV	SV roll
Audi A4 4WD	luxury car	midsize	0	0	0	0
Honda Odyssey	minivan	very large	0	0	0	0
Kia Sorento 2WD	SUV	midsize	0	0	0	0
Lexus RX 350 4WD	luxury SUV	midsize	0	0	0	0
Mercedes-Benz GL-Class 4WD	luxury SUV	large	0	0	0	0
Subaru Legacy 4WD	4-door car	midsize	0	0	0	0
Toyota Highlander hybrid 4WD	SUV	midsize	0	0	0	0
Toyota Sequoia 4WD	SUV	large	0	0	0	0
Volvo XC90 4WD	luxury SUV	midsize	0	0	0	0
Honda Pilot 4WD	SUV	midsize	2	0	2	0
Mercedes-Benz M-Class 4WD	luxury SUV	midsize	3	3	0	0
Ford Crown Victoria	4-door car	very large	4	4	0	0
GMC Yukon 4WD	SUV	large	4	0	4	0
Acura TL 2WD	luxury car	midsize	5	5	0	0
Chevrolet Equinox 2WD	SUV	midsize	5	3	2	0
Chevrolet Equinox 4WD	SUV	midsize	5	5	0	0
Ford Expedition 4WD	SUV	large	5	5	0	0
Ford Flex 2WD	SUV	midsize	5	0	5	0
Mazda CX-9 4WD	SUV	midsize	5	0	5	5

Highest rates of driver deaths

More than 46 driver deaths per million registered vehicle years, 2011 and equivalent earlier models, 2009-12

			Overall	MV	SV	SV roll
Kia Rio	4-door car	mini	149	96	54	15
Nissan Versa sedan	4-door car	small	130	44	87	51
Hyundai Accent	4-door car	mini	120	65	53	16
Chevrolet Aveo	4-door car	mini	99	65	31	10
Hyundai Accent	2-door car	mini	86	43	48	20
Chevrolet Camaro coupe	sports car	large	80	19	60	25
Chevrolet Silverado 1500 Crew 4WD	pickup	large	79	40	36	17
Honda Civic	2-door car	small	76	46	29	10
Nissan Versa hatchback	4-door car	small	71	37	33	20
Ford Focus	4-door car	small	70	55	13	5
Nissan Cube	station wagon	small	66	38	29	6
Chevrolet HHR	station wagon	small	61	34	25	9
Chevrolet Suburban 1500 2WD	SUV	very large	60	31	28	9
Chevrolet Aveo	station wagon	mini	58	58	0	0
Mercury Grand Marquis	4-door car	very large	57	33	25	0
Jeep Patriot 2WD	SUV	small	57	44	9	3
Mazda 6	4-door car	midsize	54	34	17	3
Dodge Nitro 2WD	SUV	midsize	51	7	50	40
Honda Civic	4-door car	small	49	28	21	8

Figure 33 USA Insurance Institute for Highway Safety (IIHS) highest & lowest driver death rate

It can be seen that this type of research shows that there is such a wide discrepancy between safest vehicles and the least safe. Arguably the vehicles that have the higher death rates should not be allowed to access the road network. Possibly Australia should be actively investigating this type of information with a view to developing a strategy to identifying and improving the worst performing vehicles. Refer Figure 33. Some vehicles are prone to rollover or single or multiple vehicles crashes for which we must do further research to understand why these outcomes occur.

10.8 Technological advances potentially de-sensitizing drivers

Modern vehicles with many safety features maybe providing a false sense of security for drivers to take more risks. Or as one person put it, “the modern vehicle i.e., smooth, quiet, easy to handle, may be desensitizing the driver to feeling the road conditions” such as changing traction levels on wet or damp pavements, different pavement textures and friction levels, and hence they may unknowingly push the modern vehicle harder.

Safer vehicles may indirectly contribute to increased crash numbers and safety outcomes as driver comfort, engine power, handling in emergencies or even safety applications on these modern vehicles providing increased driver confidence. For example, ESC and or other features may be causing other unexpected problems. It was also noted in discussions that ABS Brakes are considered a good safety application by just about everybody yet there seems to be minimal evidence it actually reduced the number and fatalities and serious injury crashes. It is acknowledged that some people will strongly argue otherwise, however some of the empirical evidence appears to portray mixed findings and should not be confused with ESC findings.

In one discussion it was stated that the Ford Focus or Volkswagen Golf refer Figure 54 above that the driver may be losing the feel of driving due to the technology advances i.e. electronic suspension settings, power steering, and hence become over confident and thus drivers may no longer have a good feel of the road, when the tyres, for example, are working close to their limit on a wet damp or slippery road surfaces. The first the driver knows about it is when the vehicles tyres begins to lose their grip and by then it may be too late to avoid a crash.

There may be other factors other than the vehicle design at play as found in Sweden, where AWD cars apparently feel safer to drive on wet, damp and slippery roads and hence drivers take more risks and consequently these vehicles are involved in higher numbers of crashes refer (M. Rizzi, 2016; trafa.se, 2013).

On the other hand, evidence in Europe has also shown that some relatively safe vehicles also show up in the higher crash involvement due to their popularity with certain age groups as they are relatively cheap to buy and maintain and in demand by the youth. In some countries these vehicles are considered iconic for youth and they also have reasonable high power levels. This is a bit like the popularity of older Holden and Ford cars in Australia from the 1960s which compares to the popular Ford Focus and VW Golf cars in Europe.

10.9 Are wet, dry, damp or hot pavements problematic for motorists?

Discussed with a number of researchers was the influence of damp and or greasy pavements (i.e. from dew rather than rain) potentially being a significant issue in Australia that is not currently captured when it has not been raining and, potentially police reporting would perceive the sky is clear or even sunny. Discussions focused on braking distance in wet weather versus dry and how the motorists may not perceive the change in risk in the early morning peak period, as the majority of Australian driving is done on very dry pavements with clear skies which potentially masks the perceived risk when dew is present after a period of dry weather where grease and dust accumulates on the pavement. These risks potentially comprehended and understood by motorists when there is rain physically hitting their windscreen and the wipers are turned on and water is obvious on the road surface and thus drivers change their level of alertness or driving behaviour accordingly.

It should be noted that countries like Sweden and Norway which have very long cold winters when damp, wet or icy pavements becomes normalised by drivers very quickly once the winter season commences. Hence the Australian problem of regular interchanging of conditions when the odd morning might have a damp pavement is somewhat unique. This also is a condition that may only exist in the colder southern or more elevated mountainous parts of Australia, where heavy dew and fog occurs intermittently although commonly occurs overnight in the colder months of the year.

The importance of this small detail may have been missed in crash records as the friction of a damp pavement means that braking distances are increased significantly thus forming a critical element for motorway crashes which usually requires emergency braking and maneuvering and 10m addition stopping distance can be the difference in not crashing, or being involved in an FSI crash. It might also be possible in the future to time stamp crashes and link them retrospectively to the Bureau of Meteorology “Dew Point” records for locations where crashes have occurred to see if there are crash patterns associated crashes occurring on damp pavements. Damp pavements have been described as being hard to identify by drivers due to the thickness of the film and also even experts have difficulty identifying or classifying damp pavements. Also different pavement surfaces such as sprayed seals and dense graded asphalt etc have quite different friction levels.

10.9.1 Measuring pavement friction

The interaction of the vehicle with the road pavements is a critical element in understanding crash causation. In Australia, much of the distance travel is carried out on dry pavements and hence this is the condition that motorists have the most experience. This becomes their baseline for understanding how their vehicles handle and perform in emergency braking situations. Evidence shows that pavements have the highest measured friction in winter (i.e. cold weather, when pavements are dry), however, friction reduces on wet pavements, damp pavements and in hot weather (i.e. in summer hot pavements) when the pavement become soft. In many parts of Australia we experience heavy dew and hence the sun might be shining with no clouds or rain yet the road pavement condition is very wet or damp. The hot pavement problem is uniquely an Australian condition where friction may be at its lowest.

Most work on skid resistance relates to wet roads. However, there may be situations in which the "apparent" dry road friction becomes a contributory factor in crashes. In the 1980s, Roger Hosking from TRL carried out a study investigating the effect of seasonal variations on accident frequency in the U.K. "***He observed that on most of the geographical regions and groups of roads studied, changes in dry-road skidding rates were related to wet-road skid resistance. However, he attributed this apparent correlation at least in part to misreporting of roads in the accident statistics as dry when they were actually damp".*** (G. W. Flintsch, 2012)**.**

In (G. W. Flintsch, 2012) pavement friction varies a great deal depending on the actual thickness of the water film refer (Figure 34 Effect of Water Film Thickness on Skid Measurements). Tyre tread condition can also be seen to make a big difference. It does not take much moisture to reduce the friction and under heavy dew conditions, the pavements are often very wet. It might also be considered that wider tyres might also be more prone to aquaplaning given the increased surface area and thus less friction on the pavement when a film of water is present. We have an additional problem in Australia when after long dry periods the roads have the potential to be greasy when wet and this may occur during the first heavy dew event after a dry period rather than by a rain event.

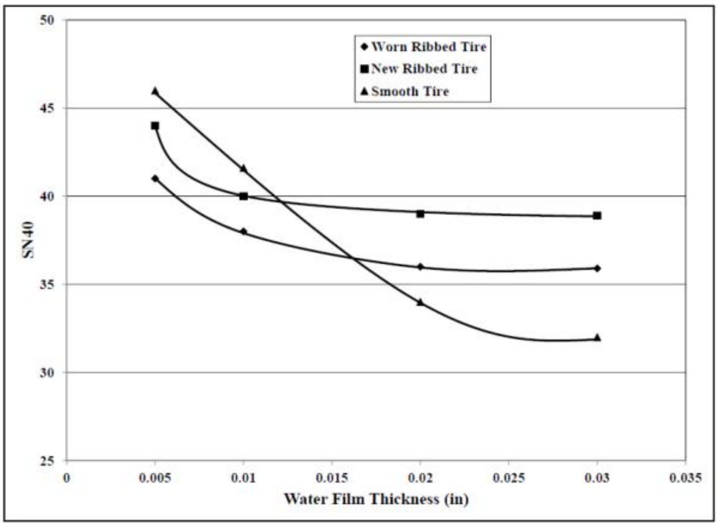


Figure 34 Effect of Water Film Thickness on Skid Measurements

Thus when road pavements are wet, damp without rain present or even very hot, motorists may not be able to perceive the increased safety risk and that they need an extra 10-20% more stopping distance when traveling at highway speeds. **This can be the difference between avoiding a crash altogether and a serious crash outcome, part**icularly if the driver also needs to swerve to avoid a collision or to avoid a kangaroo etc. As shown in (Figure 35 Stopping distance dry versus wet), from Transport and Main Roads Queensland, shows the differences in stopping distances between wet and dry pavements. At motorway speed (100km/h) on wet or damp pavements, the stopping distance can be extended by 24m. The reason why stopping distance is critical is that these types of "Events of Exposure" occurs very often on heavily trafficked or congested motorways and these events usually require heavy braking and maneuvering and hence the extra braking distance on wet, damp or hot pavements is crucial to avoiding crashes.

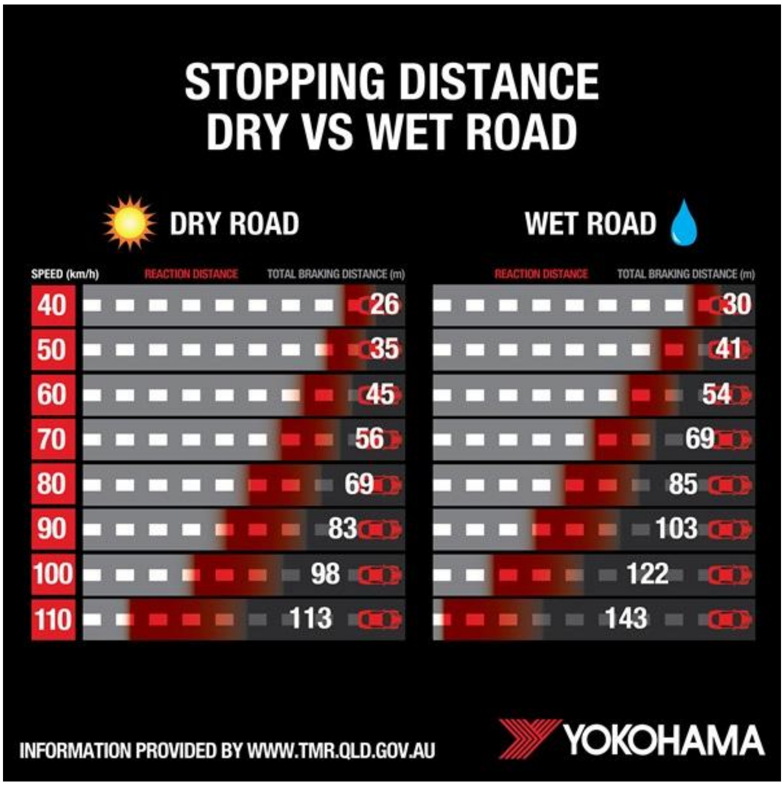


Figure 35 Stopping distance dry versus wet

As shown in Figure 36 Tyre Tread depth by speed influence on road contact with 1mm water depth Gothie (2005)(Austroads), it clear tyre tread depth and speed has a big influence on the contact area with the road pavement and thus wet weather stopping distances must increase. Thus “Wiping off 10km/h” in wet weather may be a good principle for all vehicles. The 1.6mm tread depth is 1mm above what is legal in Australia i.e. 1.5mm.

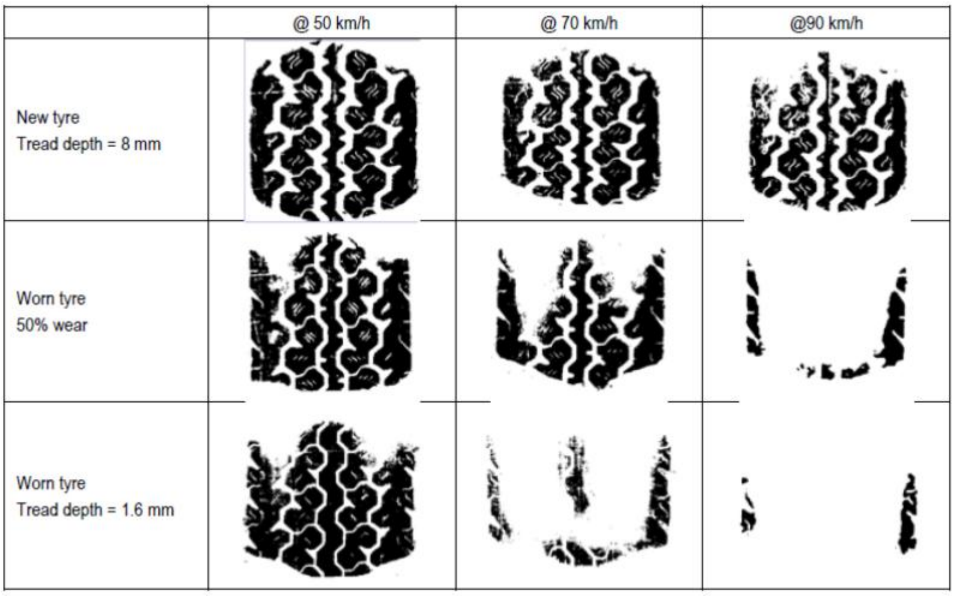


Figure 36 Tyre Tread depth influence on road contact with 1mm water depth Gothie (2005)

10.9.2 Braking distance by similar vehicle types

The following Figure 37 shows variations in braking distances of vehicles of similar weight class. They do not have the same stopping distance (i.e. a range of 37 ft difference or around 11m) which is a considerable distance, being an additional 31% braking distance (i.e. 156ft c.f.119 ft). An unsuspecting motorist changing between similar vehicles (i.e. a private and a work vehicle), may not appreciate the significant change in braking performance of two very similar vehicles.

Figure 35 above also shows the reaction time distances and for highway speeds, 100km/h are in the order of 40m and this distance is often not available to drivers when “Nucleation Events” or “Shockwave Events” occur on motorways, refer Section 9 Understanding Crash Causation from Contemporary Traffic Theory. Reaction time can be almost zero for some drivers who are caught up in a “Chain Reaction” event on urban motorways when congestion or shockwaves are present as the first driver who causes the perturbation, or the trigger of the shockwave sees the problem, reacts by applying the brakes and maneuvers to avoid a crash. However subsequent drivers have little or no time to react as they are following a vehicle who rapidly decelerates and the first visual cue they see is the brake lights of the vehicle in front braking very hard which means that the driver has lost up to 40m of stopping distance.

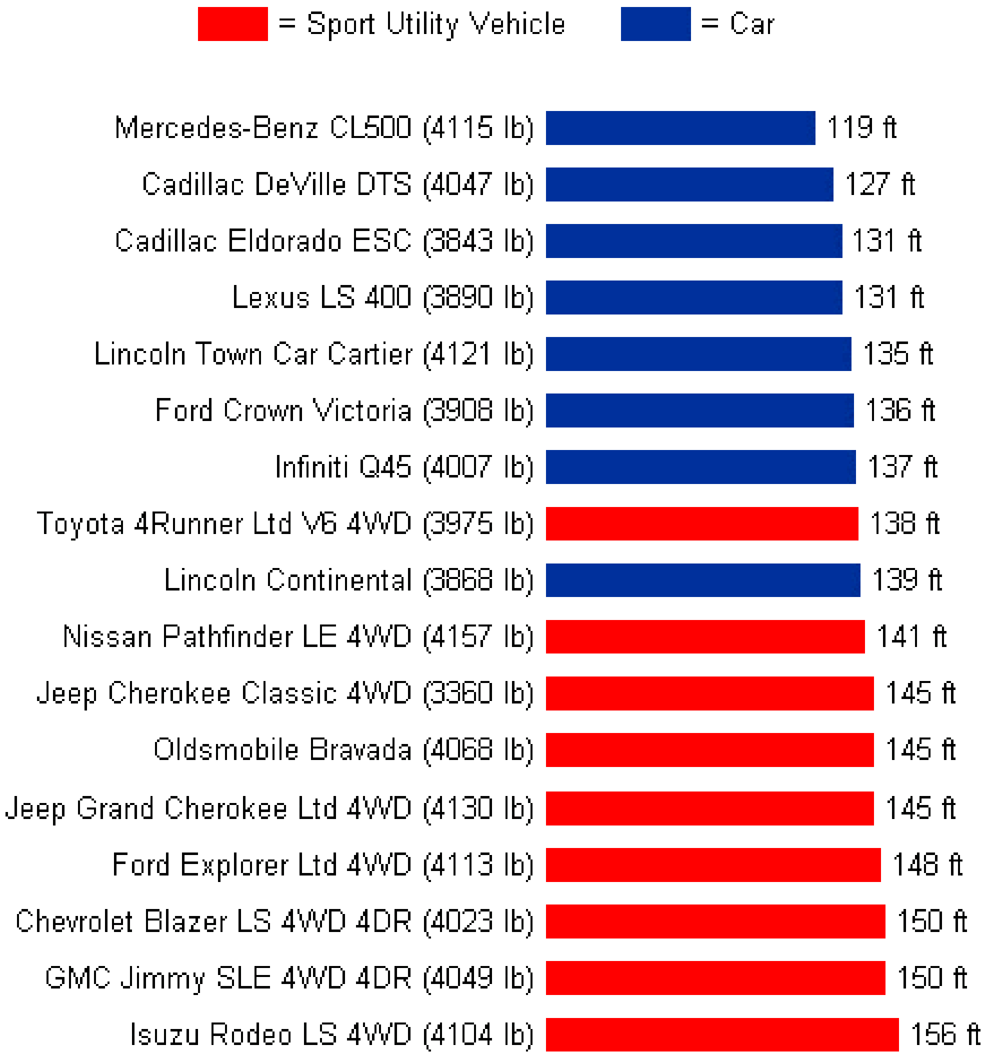


Figure 37 Variations in stopping distance of similar vehicles

11 ROAD SAFETY SCIENCE NEEDS TO BE QUALIFIED

11.1 Introduction

The Australian road toll no longer seems to be falling, refer Figure 3, at the rate that was expected based on the historical trend. Likewise hospitalised injury numbers seems to be steadily rising, refer Figure 27, despite the current high level of effort and focus on road safety and relatively high levels of investment in road safety across Australia over the past decade. This is similar in other countries that have similar approaches to road safety, refer also Figure 32 International road safety plateau performance.

This section seeks to identify some of the areas needing further scientific investigation to enable road safety programs to refocus effort. Breakthroughs will only occur by progressively making rational refinements to processes, expertise and strategy.

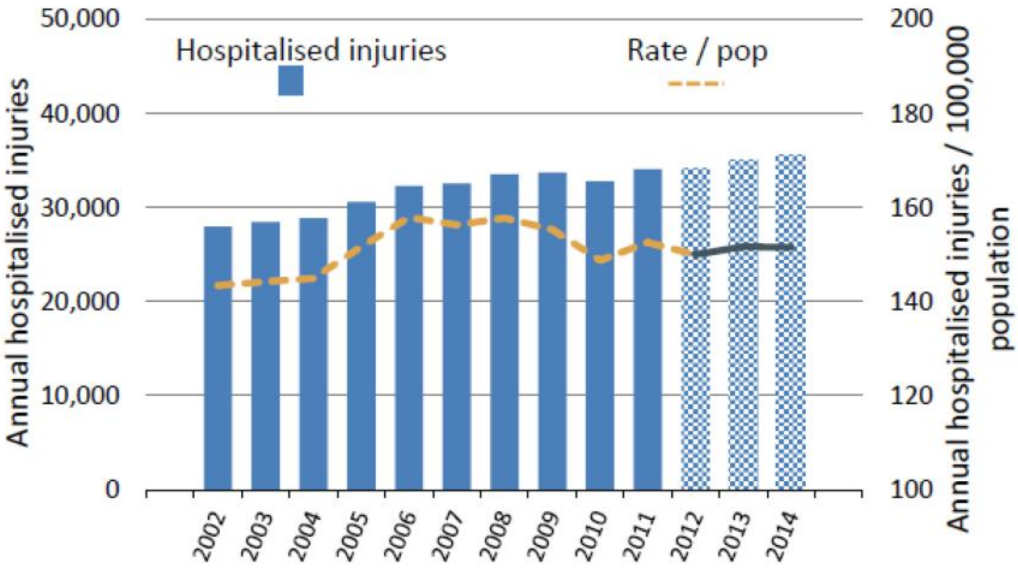


Figure 38 Annual hospitalised injuries and injuries per 100,000 population, 2002 –2014

As discussed in previous sections, many urban motorway crashes may be a result of mechanisms that are not well understood and which are unlikely to be solved by traditional road safety approaches and initiatives. Discussions in this paper are not indicating there are easy answers or "silver bullets" that are readily available on the shelf. To solve these complex road safety problems however, if the foundations of the scientific basis[122] are not entirely robust we should not be surprised when we see certain road safety performance metrics rising. When the foundations are robust and scientifically sound we should at least be able to clearly explain why our performance metrics are steadily rising without the need for speculation.[123]

As shown in Figure 28 Australia annual fatalities and injuries 1965-2030, injury are rising significantly and expected to reach 40,000[124] per annum by 2020. The rising number of crashes reveals that maybe we have not focused enough on "crash avoidance", with recent efforts on reducing the severity of the many crash events to reduce injury outcomes.

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[122] Empirical evidence of all the elements involved in crash causation and empirical evidence how solutions address each of these elements

[123] to conclude that something is the case on the basis of only limited evidence or intuitive feeling

[124] In 2017 the figure is around 44,000 well above the forecast and expectation by 2020

In the case of urban motorways which are built to the highest safety standards, it has been shown we cannot guarantee the crash outcomes as the same crash mechanisms which cause near misses also cause FSI crashes, with the difference in injury outcome explainable by 10-20 centimetres of additional vehicle contact area, or a few extra square meters of empty road space, at the exact moment of the pre-crash sequence commences. **Therefore future road safety strategies must also focus on crash avoidance and until we do we may not see significant further reductions in FSI crashes.**

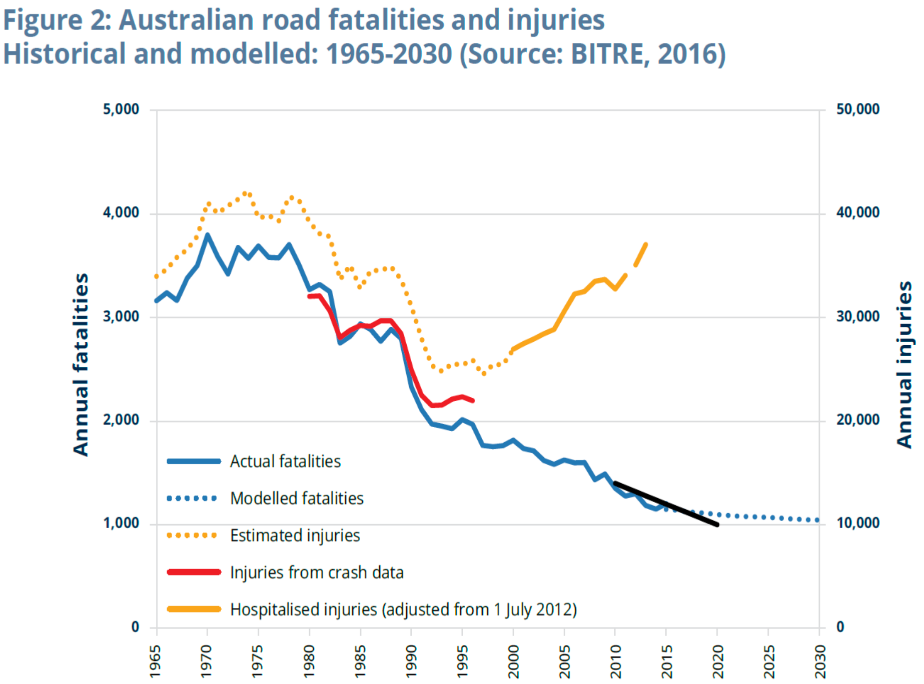

Figure 39 Australia's annual fatalities and injuries 1965-2030

The foundational science(s) that underpins road safety initiatives are important to understanding road safety outcomes. Such discussions were the focus of many meetings during the Churchill Fellowship, particularly as there now seems to be strong associations between road crashes and increasing travel demand and congestion which activate several well known traffic flow mechanisms which do not behave in a linear manner with respect to AADT, or whose crash location are not deterministic or outcomes highly predictable (i.e. "property damage" or fatality crash). The influence of these mechanisms particularly in the rising motorway casualty crash problem does not seem to be widely acknowledged.

11.1.1 Use of short-term statistics can hide crash trends

A further breakdown of crashes by month of year of Australia's national crash statistics, refer Figure 29, over the past five years reveals the variability of the monthly fatality numbers. Monthly fatalities vary between 75 and 135 a difference between the highest and lowest month of 55 fatalities. Looking at the past five years, it seems clear that large variations appear to be part of the natural variation of how crashes occur, as road safety analysts have not been able to explain these large variations by other factors (i.e. seasonal variations). In some months we seem to celebrate success (i.e. lower fatalities) and the next month we seem to be in crisis with higher numbers when this is part of the natural variation in the distribution of relatively rare and random distributed events where trends are only discernible over longer timeframes.

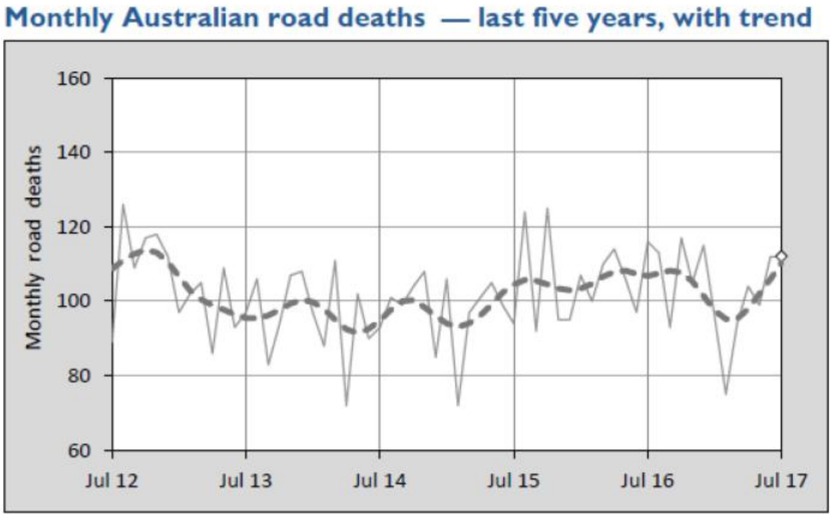

Figure 40 Australia's national fatality crash numbers by month of year July 2012 to July 2017

The short term rolling averages shown in Figure 29 are little more than a passing interest as it highlights that unless, the rolling average period is proportional to the pattern of the longer term trend, they are not particularly helpful in understanding the road safety problem and thus care should used by government agencies when conveying any meaning to these figures. It is quite disquieting when we regularly hear statistic like this month the crashes down 5% or the rolling 12 months average shows we are down 6%, as such statistics have no grounding in science when you see natural period of variations in the monthly figures of 40-50% or the natural variations in the long term trends. Such use of statistical methods is rarely found in other industries or scientific fields except maybe for financial industries like the share market, as they can be misleading, enabling short term thinking to change strategies depending on how the last short term period performed.

Road safety trends at the monthly, quarterly or yearly level cannot be relied on to show any real trend or meaning that would warrant a radical change in direction or policy. A minimum of 3, 4 or 5 year rolling averages are required to understand underlying patterns. **Statistically Australia unfortunately has seen little change in fatality crashes over the past five years between July 2012 and July 2017 where the underlying trend reveals an average of about 100-105 fatalities each month.** Refer Figure 40 Australia's national fatality crash numbers by month of year July 2012 to July 2017.

Long term gains in road safety have significantly stalled and, hence Australia has needed to reconsider aspect of the direction of road safety strategy. **The empirical evidence is clear: for more than five years in a row there is a fatality crash about every 7.5 hours on Australian roads, which is far too many**.

11.1.2 How robust is the foundational science(s)?

How do we know with a high degree of certainty the findings of road safety evaluations and research make sense from a theoretical scientific perspective and, that road safety treatments will only have the intended outcomes? How do we know that something has not changed in our transport environment (i.e. see discussion on the "Black Swan" event below), that negated something that had been believed to be true for a long period of time?

If we are going to be effective in developing road safety solutions to solve our current problems, (e.g. there are too many motorway crashes), we must be sure that our analytical models and methodologies for assessing the "effectiveness" and "benefits", of solutions, provide us with the correct answers for our time. Often assessment criteria used in business cases are based on results calculated many years ago and thus yesterday's beliefs and solutions can no longer be assumed to be still correct and thus must be regularly reassessed for currency. **If the science is not right our solutions will not be right**. Road Safety's "Decade of Action" in many ways arguably, has continued to do many of the things that were believed to be effective in the previous decade with some refocusing of emphasis and use of new language. However, was this entirely the right path to follow and, were there clues to some context changes that are now evident in road transport before this decade started? It would appear that much of the foundational empirical scientific research and theory in the "textbooks" that brought about road safety strategies like "Towards Zero", "Safe Systems" and "Sustainable Safety" has been based on fundamental thinking and fundamental underpinning research[125] undertaken some time ago, during a period with a different context for road crashes and with different technologies available for solutions and, thus they may now be in need of some review and refinement as our crash problem is now revealing itself in quite different forms.

Brought to my attention during the Churchill Fellowship was a useful book titled "Thinking, Fast and Slow" a best-selling book published in 2011 by the Nobel Memorial Prize in Economics laureate Daniel Kahneman. The book was the 2012 winner of the National Academies Communication Award for best creative work that helps the public understanding subjects such as behavioural science, engineering and medicine, all of which are relevant subject areas for improving road safety outcomes. It explains how people make decisions described as "two modes of thought", being fast: instinctive and emotional and being slow: more deliberative, and more logical.

In this context we should be somewhat concerned with the fast pace of change where rapid project appraisal and decision making processes, often facilitated through workshops, where hasty decisions are made to fast track policies and programs often promoted under the label of being clever and innovative. It should therefore not be surprising that Daniel Kahneman identified that the best decisions and solutions will only come when the slower, more deliberate and logical path is combined with the fast thinking. That is, we must do the hard yards by **first understanding problems at the elementary level and only then equipped with the knowledge gained, from fundamental research and reports written by experts, can we make faster more instinctive and emotional decisions by drawing upon our technical knowledge and experience.**

Daniel Kahneman states that ***"Intelligence is not only the ability to reason; it is also the ability to find relevant material in memory and to deploy attention when needed."***

Some potential shortcomings and gaps in science, misconceptions and traps need to be first corrected before we embark on the next wave of fast thinking in the complex field of road safety.

11.2 Do we have a theoretical basis for our current problems?

Rune Elvik in his paper titled (To What Extent can Theory account for findings of Road Safety Evaluations Studies) suggests:

"One of the major problems of road safety evaluation research, is the fact that much of this research does not have a strong theoretical basis, which guides the design of studies and the interpretation of study findings. The lack of a strong theoretical basis for research means that few

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[125] Current road safety strategies are believed to be cutting edge and new yet most countries visited indicated they needed review and correction as they were not meeting expectations.

results of road safety evaluation studies can be "ruled out" on theoretical grounds. In this respect, there is sharp contrast between road safety evaluation research and research in more theoretically mature disciplines".

Such a strong statement should stop the reader in their tracks and they must ask how did we get to this situation? Hence this Section and Appendix C- Nine Areas of Concern for Road Safety Science explores some of the potential shortcomings and gaps in science, misconceptions, and traps that need to be first corrected before we embark on the next wave of fast thinking in the complex field of road safety. It is becoming increasingly clear that some road safety findings should be "ruled out" on theoretical grounds.

Road Safety treatments usually impact two primary areas being: the **engineering effects**[126] and the **behavioural effects**. That is, the engineering treatment should provide a mechanism that reduces some effect or impact for the better and/or the treatment should provide some behavioural change that modify perception(s), or some adaption of behaviour(s) for the better.

Understanding and measurement of both these categories of outcomes are necessary before undertaking road safety analysis, hence report findings should have both measured and explained outcomes from **both engineering and behavioural theory**. Therefore Rune Elvik proposes in its simplest form, a causal chain through which a road safety measure, influences road safety can be modelled as shown in Figure 41[127] below:

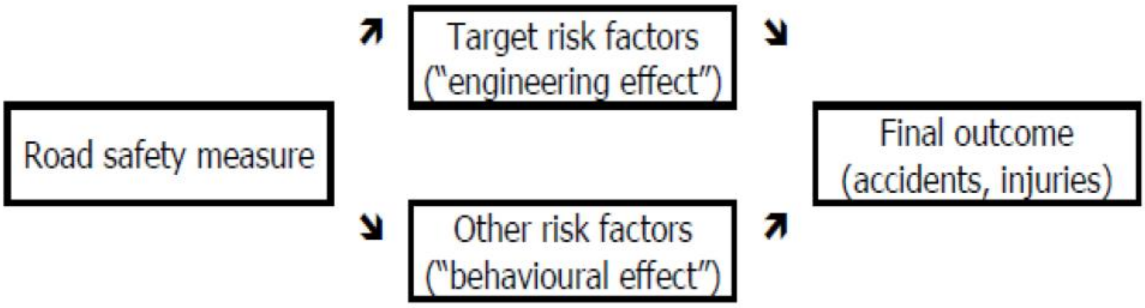

Figure 41: General model of the causal chain through which measures influence road safety

11.2.1 Unintentional Outcomes of Engineering Treatment

"Some engineering treatments, for example, can have unintentional outcomes such as a study on street lighting in Norway which showed that the engineering assessment predicted the crash reduction resulting from the provision of street lighting might have been very high (i.e. 80% reduction in crashes), however according to (Fosser & 1999) road users do adapt their behaviour to road lighting as necessarily expected. However when implemented three forms of behavioural adaptation were found:

1. *Speed increases once road lighting is provided.*
2. *Road users tend to be somewhat less alert when road lighting is provided.*
3. *Some road users who did not travel in the dark before the road was lit have started to do so".*

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[126] i.e. engineering = applied science

[127] Medical intervention effects could also be added to these effects as they need to be acknowledged as being one of the greatest, if not the greatest contributors over the past 30 years to the reduction in the road toll and the long term effects of serious injuries.

Hence although the crash rates are meant to be reduced when street lighting was added, Rune Elvik suggests there is:

> ***"no well-established theory that can rule out the possibility that the (true long term expected) number of accidents will increase, although this is perhaps not what is most likely to occur".***

11.2.2 Have we understood the true relationships between crashes and exposure?

As discussed in Section 6, Crash Risk a Function of "Events of Exposure", understanding of road crashes by some practitioners have often been assumed to increase as AADT increases i.e. a positive relationship and thus follows the relationship illustrated by top curve below refer Figure 11 Shape of relationship between relative exposure and accident rate. Thus if the rate of crashes i.e. number of crashes divided by AADT, is plotted as a function of AADT, the function slopes upwards. If, on the other hand, the rate of crashes is plotted as a function of the number of encounters discussed in detailed Section 6 Crash Risk a Function of "Events of Exposure", the curve slopes downwards as shown in the bottom curve of the graph shown in Figure 11. This negative relationship occurs because number of events representing a crash risk increases at a much faster rate than traffic volume, measured by AADT.

When undertaking road safety crash analysis, assuming crash rates rise at a certain rate with increased exposure might be inappropriate, as many other factors are usually involved, for examples drivers actually learn from experience over time, and hence they learn how to navigate a route safely despite increasing AADT. Hence there are usually other more complex factors involved which involve mechanisms outside traditional thinking and analysis and, engineering solutions. If an incorrect, understanding of these relationships is used in the analysis of "Black Spot" treatments then the analysis may arrive at wrong conclusions by predicting a higher or lower number of expected crashes.

More often than not road safety analysis will show the treatment is more effective than it actually is because the analysis method might assume an increased number of crashes would have occurred in the after study, due to increased AADT, whereas drivers often learn over time, or there are other factors (i.e. safer vehicles), which reduce the impact of crashes with respect to increasing AADT.

Analysis methods often don't have adequate controls[128] and ignore factors like vehicles are safer in the after analysis period, as vehicles would usually be five years newer and, especially in the past 10 years vehicles are much better equipped and it would be expected they would provide improved crash outcomes. Other road safety initiatives in the past 5 years which may have contributed to the finding, such as increased enforcement, road safety education and in the case of rural roads sealing of shoulders on A and B roads, based on other road programs that occurred widely across Australia over the past 20 years.[129]These works may have, for example, reduced driver fatigue and thus crash risk at the "Black Spot" site.

It is likely that road safety risk category will change with increasing AADT and pavement types and crash type is also likely to change with increasing AADT from "run off the road" to "head on" to "vehicle to vehicle" etc. Thus treatments will vary for each AADT category as context must be understood. It is possible that many treatments have not been aligned with these changing contexts.

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[128] All Road safety studies should use a mathematically significant number of control site to verify improvements

[129] Refer VicRoads towards 2000 strategy in 1991

11.2.3 Have we acknowledged systematic errors to the extent that we should?

When undertaking analysis of road crash treatments it is essential that systematic errors (i.e. data error, and errors in the methods used), are reported so there is a full understanding of the level of confidence or certainty around the findings. This detail can then be used to inform subsequent readers and researchers to provide confidence in the findings and thus informing the extent that such research should be applied by practitioners.

An example of systematic errors occurring in before and after road safety studies, as the traffic volumes used are often AADT estimates, and hence have significant potential for error. Another example includes the relative change in vehicle age between the before and after the study is usually not reported. Also not reported are the progressively improved traffic engineering and road design standards, changes in pavement conditions including friction levels and, changes to delineation and maintenance activities all of which often have not been monitored throughout the assessment period and, hence ignored in evaluations.

It has often been observed that researchers have carried out their road safety studies in batches at their desktop without ever visiting the crash locations or having a photographic record of the before, during or after conditions. An evaluation of 3-5 years is a long period for other factors to influence findings such as a nearby construction site reducing speeds, or changing (both positive and negative) traffic volumes over an extended period of time and, changes to traffic signal phasing or plans.

There appears to be little understanding of systematic errors in the measurements used in much of the analysis, which should always be reported together with their findings, including with a sensitivity analysis of any estimated data used. Regression analysis to remove randomness is often not undertaken or excused in footnotes as not being necessary.

11.2.4 A complex science requires regular reassessment and correction

The primary reasons for recent rises in FSI crashes on European motorways remains somewhat unclear amongst many long-term and experienced road safety researchers and practitioners, whom I met on the Churchill Fellowship. Open discussions provided different perspectives revealing considerable speculation about such things as increased mobile phone usage causing a distraction,[130] lower levels of enforcement and younger, inexperienced drivers using the road since the recovery after the global financial crisis as they are now buying their first cars. However, most researchers openly admitted they were speculating and did not have sound evidence, which leads to one of the major problems being the science of attribution and the science of understanding trends.

11.2.5 Perspectives are not necessarily scientific facts

Just because some measures in the before and after study have changed favourably to being either lower or higher does not automatically imply that the correct attribution of all the mechanism(s) involved in the change has been identified, or that the stated conclusions in the report have followed the necessary scientific methods and rigour.

Humans have an innate tendency to associate ideas and concepts to explain circumstances they see, and these explanations are completely rational, logical, convincing and plausible, to others who may subsequently read their reports and may readily believe them. However sometimes they might not

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[130] This should not be speculation as this should be a routine part of investigation of all fatalities crashes. Many crashes occur in Australia where there is no mobile phone coverage and thus for these crashes this factor can be excluded.

contain the whole truth and often they only form part(s) of the truth. Humans naturally warm to narratives and find comfort in patterns and associations that explain things or circumstances they see to expect to find (i.e. optimism bias). Thomas Kuhn in his renowned book The Science of Revolutions quotes that "*Philosophers of science have repeatedly demonstrated that more than one theoretical construction can always be placed upon a given collection of data*". This highlights the dangers of holding too much confidence or certainty around a single conclusion about a set of data or research findings.

Different opinions can be held by different people seeing the same problem or situation. To illustrate this problem of attribution let's assume three observers see a vehicle going through a red traffic signal at an intersection, and each comes to their own conclusions as follows:

- The first observer states the driver is a careless driver,
- The second observer states the driver must have been distracted talking on their mobile phone
- The third observer states the driver must have been daydreaming or not concentrating.

When the actual driver was asked why he went through the red light he said he was taking his heavily pregnant wife to hospital and that he had slowed at the intersection, almost to a stop, looked both ways and then safely proceeded through on the red light when he saw the crossing road was empty and was safe to enter. All three observers witnessed the same event attributed the cause of problem differently and their attributions all seemed plausible, (i.e. they are rational, logical and convincing and aligned with current road safety narratives that this action was inherently dangerous or careless in all circumstances). However, did their attributions form any part of the truth or reflect their own bias? Although illegal motorists could safely navigate unsignalised intersections before traffic signals were invented albeit at a higher average crash risk

11.2.6 Can recent rises in crashes be explained in terms of historical attributions?

Hence one of the key topics under the microscope during the Churchill Fellowship is the problem of correct attribution and how do different researchers know they have correctly attributed all the factors associated with these very complex and unique problems to their solutions or evaluations. If we have incorrectly attributed just some of the reductions in the road toll over the past 30 years to the wrong or an incomplete set of attributes or principles, any subsequent rise in crashes might come as a surprise. Following many discussions with researchers in Europe, this appeared often to be the case where they openly admitted they could not provide plausible explanations or fully explain the recent rises in the road toll or rises in the number of serious injuries crashes hence (possibly the context is changing).

In addition, if there has been any incorrect attribution in the past this will significantly change the benefit/costs ratios for road safety programs, potentially lowering the benefits these programs provide the community. For many years first world countries have been following the reductions in the road toll and then attributing this or implying through narrative refer Figure 94, that this occurred primarily due to the effectiveness of their road safety programs. Whilst this is clearly true there have been many other factors that have also contributed to reducing the road toll that often gets inadequate recognition or mentioned in road safety programs.[131]

There is also another trend in road safety attribution due to the inability to clearly breakdown where

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[131] Refer Appendix B, An alternative perspective on the road safety narrative.

the actual benefits lie for a particular road safety initiative and, thus there is an often an "open admission" that it has been the collective effects of a myriad of safety strategies targeting a wide range of initiatives that collectively resulted in reductions in the road toll. That is to say, no one strategy is effective on its own but collectively they all seem to work. This message seems rational, logical and convincing when the road toll has been steadily reducing, however, it comes a little unravelled when we continue to follow similar strategies and programs and the road toll no longer continues to fall.

The historical record would have expected the road toll to fall at similar rates, however there now appears to be a statistically significant plateauing[132] or in some cases rising, which has been seen in Australia and many other first world countries. These admissions appear to be evidence that road safety attribution may not be as well grounded as a science as we thought or, alternatively there has been a significant context change that these countries have been collectively slow at recognising and realigning their programs too. It is possible both these problems to a degree are the current reality.

11.2.7 Correctly attributing road safety benefits is crucial

Despite record investments in road safety in Australia the FSI crash numbers in Australia have plateaued, and this is also seen in many first world countries also focusing heavily for the past 30 years on road safety i.e. Norway, Sweden, Holland, Germany and Belgium. One of the common responses from experts met on the Churchill Fellowship was that "crash numbers were increasing on motorways and divided highways and **we don't understand why**". This is a collective problem where progress on road safety seems to have stalled since the beginning of the decade, refer Figure 32 International road safety plateau performance. When the same or similar phenomenon is seen across many countries, it is either a major coincidence or highly probable that there has been a fundamental contextual change which is simultaneously affecting all these countries. Reliance on crash reductions factors and treatments used effectively in the past may not be so appropriate when context change occurs. Often these factors or supporting evidence were developed more than a decade ago with very little review, correction or substitution with new treatments supported by strong empirical evidence.

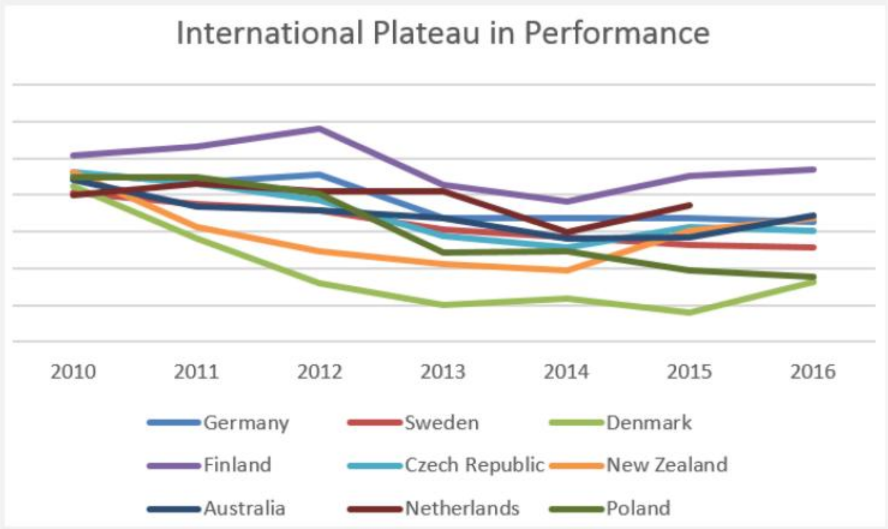

Figure 42 Evidence of International road safety plateauing (2010-2016)

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[132] Refer Figure 42 Evidence of International road safety plateauing

A number of clear explanations emerged during Churchill Fellowship discussion for the apparent rise in crash numbers being that:

- first poor or incomplete attribution as to why the crash rate fell rapidly over the past 20-30 years. This includes attribution of both the primary causes of road crashes and the effectiveness of road safety programs and solutions;

- second poor or incomplete metrics associated with the economic benefits of various treatments resulting in resources targeting certain treatments that are less effective than claimed particularly if used in an inappropriate context;[133]

- third something(s) in the context of road traffic or transportation has changed which are contributing to increased road crashes such as new modes of travel, mode shifts including more pedestrians, bicyclists, and motorcyclists, the age profile is changing (more elderly), road design changes (wider roads with more lanes), vehicle size changes and vehicle design changes (both good and bad) with more smaller vehicles mixing with larger vehicles and increased trucks numbers, increases in travel demand, the modern vehicles are desensitising drivers feeling the road conditions until the vehicle begins to slip, and reduced investment in road maintenance;[134]

- fourth being slow to recognise and react to the changes in context (i.e. the “Black Swan”) discussed below and which are related to declining traffic conditions, which requires new programs based on new research which effectively targets the newly identified problems and causes.[135]

The last point above became clear in the Churchill Fellowship study where specialists agreed they did not know why crash rates were rising and suggested it might be either this or that. However to date they had no solid evidence to prove their ideas. They expressed that there was a sense of urgency from the community to quickly come up with credible new programs and initiatives. that were convincing as their leaders had an appetite to get the “Decade of Action” back on track.

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[133] Earlier in my career I noticed that various road safety treatments had additional weightings factors that focused program priorities and improved various initiatives chances receiving funding. Such approaches lead to false beliefs by practitioners and inaccurate messaging given to the community regarding the effectiveness of certain treatments. Over time these treatments do not provide value for money and deliver less road safety benefits for the community. Usually these measures ignored other side effects such as increased congestion as being only a few extra minutes of travel, however, the accumulative safety effects of increased congestion at the network level may now be coming home to roost. Due to the likely relationship between increased demand, increased congestion and increase crash risk discussed throughout this report

[134] One parallel example of things changing was mentioned in meetings where Variable Speed Limits were used successfully in the Netherlands to reduce shockwaves and thus reduce congestion on motorways 10-15 years ago, however this treatment no longer appears to work. An understanding of contemporary traffic theory would reveal why this might be the case as the historical traffic conditions and the types or strength of the shockwaves or nucleations events which formed 10-15 years rarely exist today as the shockwaves change form with increasing traffic density. So what worked in one situation in the past may no longer work at all today and hence transferring (copying) road safety initiatives to different countries and contexts does not guarantee their effectiveness.

[135] This is primarily due to the long lead times for research to be organised to target the new and emerging problems. Fast tracking and rapid appraisal processes or blindly copying treatment done elsewhere, offer no time to undertake the necessary fundamental research or to gather the necessary background knowledge from other experts and the new fields associated with the changes in context and thus simplistic suggestions are often implemented without proper research, trials and analysis.

11.2.8 Solving more difficult problems requires a significant change in thinking

An alternative narrative relating to understanding these complex problems is that the road toll has been reduced over the past 30 years primarily by picking the relatively low hanging fruit, by targeting specific problems in the road network that have accumulated in a relatively small number of fixed and known locations (i.e. "Black Spots" or "Black Lengths") as well as addressing obvious areas such as alcohol, drugs and speeding etc.

However for the road toll to be significantly reduced further it will come about by understanding that problems now occur far more indiscriminately across the road network occurring anywhere at any time. This problem is an order of magnitude harder to solve. This requires a whole new level of thinking and, new approaches requiring new disciplines (i.e. technology based), wherein the future road safety may need to travel with the vehicle providing drivers with another set of eyes and another set of hands with onboard systems and smart tools that will avoid crashes.

As Albert Einstein stated that *"We cannot solve our problems with the same thinking we used when we created them"* hence new tools are needed to solve the changing nature of the road safety problem described in Sections 7.1 Increased volumes increases crash risk above. As each road crash has unique circumstances and needs to be considered as a highly complex scientific problem to understand all of the mechanisms involved. To better understand this complexity it is proposed that there are a number of critical problems with current approaches to road safety which need to be recognised and rectified through new approaches and methods before we can improve the effectiveness of road safety treatments and, before we can significantly reduce the road toll.

Whenever complexity and potential for ambiguity exist it is possible that sometimes we may have difficulty selecting the right course or direction. This is because often we have not fully appreciated or foreseen the full consequences of our path(s) of inquiry, which always has limitations or we have been blinded by motivation(s) and sometimes biased by our own optimism[136](i.e. we all have various Scotomas). Nine critical problems were identified from Churchill Fellowship discussions and from the subsequent material provided, and which are discussed in detail in Appendix C. The nine areas of concern for road safety science as follows:

1. The Problem of Attribution (Scotoma - partial field of view)
2. The Problem of Diagnosis (Incorrect Assumptions)
3. The Problem of Investigation Bias (False Beliefs and Assumptions)
4. The Problem of Copying without understanding Context (Blind Faith)
5. The Problem of Changing Circumstances (Disruption)
6. The Problem of Narration Bias (Preconditioning of Expectation)
7. The Problem of Simple Explanations (Myth Busting)
8. The Problem of Rare Disruptive Events (Revolutions – paradigm shifts)
9. The Problem of Whether Theory Can Explain Analysis (Evidence and Justification)

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[136] Optimism bias (also known as unrealistic or comparative optimism) is a "cognitive bias" that causes a person to believe that they are at a lesser risk of experiencing a negative event compared to others.

12 THE IMPORTANCE OF THE BEHAVIOURAL SCIENCES

This section summarises the many discussions with behavioural scientists identifying a number of relevant issues that need to be further explored. After many years of contribution, the importance of the behavioural sciences in the road safety field may still be just beginning to emerge and be accepted widely as mainstream. As discussed in this report now that the motorway crash risk is beginning to be understood, it is likely that the behavioural sciences will be critical to providing solutions but only after thorough research has been done in consultation with vehicle designers, road designers and traffic specialists (i.e. all solutions must involve a multi-disciplinary approach. It is also likely that the motorway safety problem will inform other crash problems, such as a number of rural road crashes as motorists seem to be poor at assessing risk, often not realising the complexity involved and consequences of the risks they take.

This is likely to be because the chance of being involved in an FSI crash is very low[137] and often considered that serious crashes only happens to others (i.e. the bad drivers). Hence human perceptions about safety and risk are based on what they drivers observe and the messages they distill from other sources such as the media and advertising campaigns. Therefore this field needs to be studied and fully understood before we can develop strategies to change these long-held perceptions. Human error increase when motorists are faced with increasing complex conditions, and the increasing traffic volumes means there is less avoidable recovery space when drivers make these errors.

We can see in Figure 43 from a review of road safety topics in literature, that on the left there has been a continual rise in road safety behavioural studies and traffic research over the past 100 years, whilst the vehicle and road infrastructure shown on the right is in decline. This is a good sign for the behavioural sciences and traffic-related fields, however, the two fields on the right side should be raising alarm about current state of research priorities. Given discussions in other sections of this report that the vehicle design and vehicle safety systems and, in particular, road design which has been substantially neglected by academia for the past 40 years as it has been considered to be a mature science which is far from the current reality of increasing road congestion and crashes.

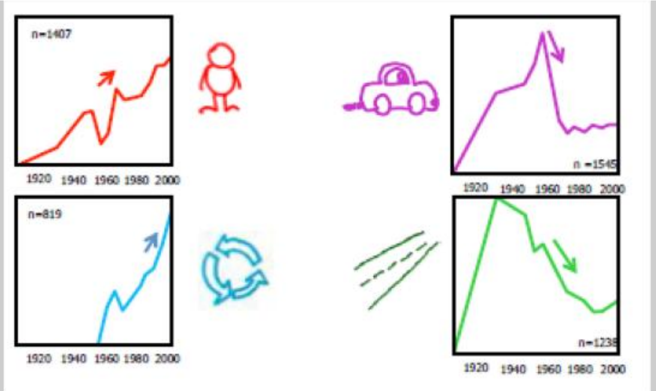

Figure 43 Road safety topics in literature over time

As discussed in Section 10 all Road Safety Programs need to investigate both the engineering (i.e. road infrastructure and vehicle effects), the behavioural effects and, potentially the medical

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[137] The perceived risk of a fatality therefore to motorists is very small, (i.e. 1 in 192,000,000km travelled or mathematically a 0.0000000052 chance of occurring for each kilometre travelled or a chance of 0.0000067 chance per year of driving based on 15,000 km per year) or one in 13 lifetimes of driving based 60 plus years of driving at 15,000km/annum.

intervention effect[138]s of all treatments using robust scientific, probability-based assessment methods to ensure benefits of solutions and treatments are attributed accurately. The Churchill Fellowship meetings reinforced that there will only be improved outcomes when road design, traffic engineering, and behavioural sciences are fully integrated and this seems to be advancing well in both Sweden and the Netherlands.

As discussed above, motorway driving is becoming increasingly complex and thus the rise in crash numbers over the past decade should not come as a surprise, as behavioural scientists for many decades (i.e. since the early part of the industrial age), have understood humans make more errors when faced with both the unfamiliar and the complex. The complexity of the issues involved in the majority of motorway crashes is such that it is difficult to warn motorists of a sudden event which is triggered by another driver's inappropriate action, a forced lane change maneuver, or a sudden braking event unfolding just up ahead, often just outside of their line of sight, and which instantly increases the risk of a crash from being very low to extreme. As these extreme events are so rare compared to the motorists overall driving experience, drivers are not able to become familiar with these events, which requires sudden decisions making for which drivers are either not adequately trained or in the moment they are not mentally prepared (i.e. alert or distracted).

During the period before the increased crash risk becomes obvious, there are few, if any, obvious visual cues that motorists are able to read, however it is possible with today's leading edge ITS tools to be able to reliably predict these pre-conditions 5-10 minutes ahead using smart traffic systems and warn motorists via VMS and by using Smart DVSL systems refer Section 14,Motorways Speed Management for Efficient and Safe Operations).

Simple precautionary messaging is often used in Europe when there is a chance of congestion or increased crash risk, refer (Figure 44 Typical VMS sign used to warn driver of changing conditions and increased crash risk).

Figure 44 Typical VMS sign used to warn driver of changing conditions and increased crash risk

Now that the urban motorway crash problem is beginning to be understood it is highly likely that behavioural scientists will be able to greatly assist in developing techniques to influence driving behaviours through improved: educational programs making motorists aware of associated risks engineering solutions; vehicle safety applications; refinements to the design of infrastructure; and, through appropriate warning messages provided on-route in the vehicle, or in the roadside, as to the changing traffic conditions which aligns with the measured real-time increased crash risk.

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[138] For example faster access to medical support, and improved medical interventions leading to improved outcomes

12.1.1 Behavioural science how is Australia tracking?

There may be many differences of opinions as to how well the "integration of the behavioural sciences" is progressing in Australia as at some levels it appears to be occurring extremely well. Fundamental research is being undertaken to identify and understand problems, however, is there commensurate rigor being applied to the development of solutions that are proven effective before widespread implementation? However, the required level of experience and practice (i.e. analysis of subjects to understand human behaviours as they relate to road safety) may not be consistent across Australia, particularly at the higher academic levels, as witnessed during the Churchill Fellowship. Such direct comparison is difficult as the author can only compare what has been observed personally in his home State or at the national level during road safety meetings, training courses, and attendance at conferences and seminars. Hopefully, this observation is because of limited access and exposure to published Australian academic findings and, limited access to other Australian State's research which demonstrates rigourous methodologies and control groups etc.

On the other hand the appearance of limited integration may purely be the fault of the state of road design and traffic engineering research in Australia which seems to also have been largely neglected over the past 3-4 decades. This has occurred as academics have shifted their interests to pursuing other parallel aspects of transport where there is more interest and financial support e.g. other transport modes and Connected and Autonomous Vehicles (CAV). This shift may have occurred on the belief that road design and traffic engineering are mature sciences, for which evidence now clearly shows these fields now require considerable more research and a long period of catch up to tackle the critical issues facing the community with increasing road congestion and its causal link to worsening road safety outcomes. Hence from observation the behavioural sciences do not appear to be academically integrated or connected with road design and traffic sciences to the extent witnessed in Europe and hence their messages are not being heard so clearly by practitioners. The behavioural scientists associated with road safety need to work in collaboration with the other disciplines (i.e. traffic and road design), which often does not seems to be the case or at the level necessary to improve road safety outcomes.

Discussions highlighted that the field of behavioural science in transport and road safety compared to behavioural science in other fields is still emerging and forming and thus should not be considered to be a mature science. Road safety is a very complex field as the communities associations with modern transportation systems and road networks are still evolving and changing rapidly, as road transport is both maturing and at the same time transforming with new and emerging modes of travel and, changes to mode share with (e.g. changes like E-bike, E-cars, mopeds mobility scooters and increased public transport usage) and, increased walking and cycling, which is rapidly changing the mix and types of crashes. Therefore, there is the need for this research to expand into new areas as the changing context means new crash problems are emerging. Road safety spans such a broad ranges of fields with so few behavioural scientists qualified, mentored and trained across the breadth of the different subject areas involved.

12.2 Examples of new understanding in behavioural sciences

Many examples were provided during the Churchill Fellowship of important new learnings that are emerging once appropriate behavioural science resources and training are applied to the road safety problem. However, the clear message from discussions was that the behavioural science field is still forming and many subject areas are still yet to be studied. The importance of the behavioural sciences was highlighted by recent examples of findings from their research and which include:

- When riding a bicycle audio (sounds) and (maybe even tactile by sensing the different pavement surfaces for friction levels) have now been shown to be crucial to riding safely and therefore listening to music through earplugs takes these senses away resulting in negative outcomes. (Hagenzieker);

- The E-bike has changed the centre of gravity of bicycles for braking and cornering compared to normal bicycles and, older drivers who often purchase these do not adapt to the change having a much higher involvement in serious injuries and fatalities, usually by hitting objects or the pavement rather than colliding other vehicles. Due to the more fragile physique of the older rider, they die often from subsequent medical complications. Thus behavioural scientists are suggesting that these older riders need to be retrained or given special training particularly if they have been involved in any form of crash or safety incident. Hence a lifetime of experience driving cars or riding a bicycle does not translate to these new modes and hence training courses focused on relearning and re-education for these new modes is needed to be developed and implemented (Hagenzieker);

- The younger drivers start to learn to drive the safer drivers they are over their entire driving life. Refer (J. Langford, 2005), refer (Figure 95 Relationship btw age of learning to drive and crash involvement), a message generally not heard by young people today as they are repeatedly told they are more dangerous. Thus the later they learn to drive (i.e. in Australia they are currently delaying the time they get their license), appears to be linked at least in part to current policy settings, means in the long term this might be “false economy” and may shift or spread the crash risk to later in their driving life;

- That older drivers are considerably safer than general drivers if they drive more than 3000 km per year as it seems like as with most things in life, practice and or training is the critical issue refer (Figure 96 Annual crash involvement for different driver ages, controlling for annual mileage). So the older drivers are often criticised in the media when there is quite a different narrative in the research data when all the facts are known. Therefore over simplistic narratives can be both misleading and lead to wrong solutions;

- That advanced driving skills such as skidding training on ice or snow do not work and waste time and money. In the past apparently based on research, advanced driver training was actively encouraged by road safety professionals including here in Australia. However behavioural science research has shown that teaching motorists how to completely avoid snow or ice or getting into a skidding situation is far more beneficial than training for it.

All these insights have the potential to reshape our messaging in the community about older and younger drivers which will break current stereotypes including in the case of the Netherlands that the majority of bicycle crashes do not involve the motor vehicle at all, refer Appendix A Section 1.6 The problem of the narrative bias (Myth busting), and Section 1.7 (The problem of simple explanations), as simplistic messaging often masks the underlying truth leading to poorly focused programs and campaigns usually which have been focused on stereotyping a particular group or a particular cause of crashes which might represent a very small percentage of crashes and should carefully considered when used to inform policy. Hence many drivers think they are responsible and don’t relate to these campaigns however they have similar order (level) of crash risk.

12.2.1 Traditional technical solutions are not working as well as expected

Informative discussions with behavioural psychologist Dr. Chantel Merkx, Rijkswaterstaat (RWS), Utrecht, Sweden indicated there is now "***significant evidence that traditional technical solutions to road safety are not working as well as experts once believed*". Therefore further understanding of human behaviours is likely to improve solutions beyond that which is currently provided by engineering. Therefore getting behavioural psychologists involved in road design and road safety audit training is considered very important, as well as in many of the aspects relating to the increasing complexity of the driving task as discussed throughout this report.

At RWS, behavioural specialists are actively involved from beginning to end in the road design process undertaking tasks such as analysis of the driver's perspective of a trip from various road users perspectives such as:

- the young, novice, professional and older drivers and, all other road users perspectives such as pedestrians and cyclists;
- the location of tree plantings and signage;
- what drivers and road users are able to see and are capable of comprehending in time and space;
- the number and complexity of decisions required in time and space;
- driver's willingness to respond to, or ignore risks; and,
- driver's expectancy of oncoming traffic.

12.3 Highway hypnosis and velocitation

The topics[139] of "**Highway Hypnosis**" and "**Velocitation**" arose in discussions with behavioural psychologists Dr. Chantel Merkx. Further investigation tends to suggest this issue may have some applicability to long distance driving on motorways and highways in Australia, as drivers regularly travel long distances on many different road types which form contiguous routes.

For example, Australia urban motorways are now often connected by higher speed roads to interstate and regional centres via rural motorways, thus the urban motorway is regularly used by long-distance drivers where the alertness level of the driver may be dulled after many hours of high-speed driving. After driving many hours behind the wheel the driver can turn into an autopilot mode and thus when they are suddenly faced with rapidly changing conditions and the more complex situations that occur, for example as they approach urban centres, and thus may not respond appropriately. Such conditions are quite different to what has been encountered over the previous hours. This increased complexity requires increased alertness and faster reaction times[140] and any sluggishness or delay in reaction time, or any over-reaction may result in a crash for themselves or for other vehicles in the nearby vicinity.

***"Highway Hypnosis"**, also known as "white line fever", is a mental state in which a person can drive a truck or other vehicle great distances, responding to external events in the expected, safe and correct manner with no recollection of having consciously done so. In this state, the driver's conscious mind is apparently fully focused elsewhere, while seemingly still processing the information*

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[139] Definitions from Wikipedia

[140] Road design standards use 2.5 seconds reaction time for rural roads and 2 second for urban roads, thus what happens in the transitions? Are these numbers right when a driver has been driving for 3 or4 hours? We may need to revisit the research.

needed to drive safely. Highway hypnosis is a manifestation of the common process of automaticity, where the conscious and subconscious minds are able to concentrate on different things. If you ask a driver what he remembers of the last kilometre they would have little accurate recollection of what they saw or did". (wikipedia)

"Velocitation" *is a phenomenon caused by driving for long periods at high speeds. A driver may experience "**Velocitation**" when coming off of the highway; the change in speed makes the driver think that the car is going much slower than it actually is. This is a common occurrence after a long stretch of country driving and then slowing down for a country town".*

"The concept of "Highway Hypnosis" was first described in a 1921 article that mentioned the phenomenon of "Road Hypnotism": driving in a trance-like state while gazing at a fixed point. A 1929 study, Sleeping with the Eyes Open by Walter Mitty, also dealt with the subject, suggesting that it was possible for motorists to fall asleep with their eyes open and continuing to steer. The idea that the unaccountable automobile accidents could be explained by this phenomenon became popular in the 1950s. The term "Highway Hypnosis" was coined by G. W. Williams in 1963. Building on the theories of Ernest Hilgard (1986, 1992) that hypnosis is an altered state of awareness, some theorists hold that the consciousness can develop hypnotic dissociation. In the example of "Highway Hypnosis: one stream of consciousness is driving the car while the other is dealing with other matters. Partial or complete amnesia related to the time spent driving under "Highway Hypnosis" can develop for the driver involved". (wikipedia)

12.3.1 Could we have an undiagnosed problem in Australia

Having personally witnessed several drivers appear to go to sleep in front of me on rural motorways it is highly likely that there is some connection with crashes on urban motorways where freight and recreational travel in Australia often involve very long distances of motorway driving into and through capital cities or larger regional centres. Under these conditions, driver's reaction times may be slow or they may not even react at all, thus they are likely to be contributors to at least some motorway crashes. "Velocitation" is a real phenomenon as I have experienced this regularly when driving in the country for 3 or 4 hours and then needing to slow down for a town where you feel at 60km/h you are almost stopped or driving too slow for the apparent conditions.

Further research is needed as these problems are likely to lead to certain types of crashes which are probably hidden within the crash records and, may only come exposed by interviewing drivers and others involved to understand the circumstances that lead up to the crash. A clue from crash records may be apparent from knowing the motorists residential address in relation to where the crash occurred, (i.e. how far from home have they travelled). It is possible that we may need to improve the design of the transition zones between rural motorways and urban motorways where a tourist or a regular driver who has been driving in autopilot mode for many hours, and then suddenly, arrives at the more complex urban motorway, with higher traffic volume with heighten crash risk and hence drivers must be alerted.

It may be that some form of transition zone messaging,[141] speed transition or other gateway treatment (i.e. a form of "self explaining roads")[142] that allows these drivers to be progressively alerted and perceive appropriate cues they are entering a zone of increased crash risk, which is now

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[141] Refer Figure 44 Typical VMS sign used to warn driver of changing conditions and increased crash risk

[142] Self explain roads where the design of the road reflects the speed to travel. In this case the design of the roads should explain to the driver the increasing complexity, requires increasing alertness. Although the concept of self explaining roads is well know it can be difficult to put into practice as treatments are often subjective and difficult to measure and effects are often not measured.

evident on urban motorways or motorways with 3 or more lanes and greater than 90,000 veh/day. This phenomenon has been recognised in road design for many years as increased reaction time is allowed for in the design[143] of rural roads. However how does this design consideration translate to drivers on the road, where the drivers need to be alerted to the changing road conditions which may not be inherent it what they observe?

Research studies are required by trained behavioral scientists to hold interviews with drivers and others involved in crashes to reveal new insights into crash causation as the driver's context (i.e. the distance they may have driven before the crash), how much sleep they had in the past day or week, and the activities they performed in the period before the crash, seems to be critical pieces of information that have not been well studied. The current regime where we do not look at "property damage" crashes, which includes vehicles that can have serious damage and which are completely written off, means we are potentially failing to pick up on a much larger problem that needs to be researched. We often wonder why there are increases in FSI crashes involving single vehicles running off the road but the cause of these crashes cannot be understood without studying pre-crash driver information which is currently not collected, refer Section16. Since Australia cannot afford in the next 50 years to put safety fences on all 900,000 kilometres of the road network thus avoiding crashes through other mechanisms needs to be a main focus of effort.

12.3.2 Interviews with drivers may reveal the cause of many crashes

The difference between a bruised shoulder that may show up the next day after a crash and a fatal brain injury or injury to another vital organ is often only 150mm difference on where the crash forces impact on the human body. Obviously it is not possible to interview a dead driver to find out the true cause of a crash, thus data needs to be obtained from other databases and sources other than police records such as interviews with survivors, family and work colleagues and the drivers of "property damaged only" crashes, as determined via towed away vehicle registers and insurance claims. It is particularly important to gain more knowledge of the cause of single vehicles occupant "run off the road" crashes which seem to be a major cause of fatalities in rural areas and thus most of these crashes are not currently reported by the police, however, may provide a valuable source of new information[144].

It would appear we are seeing many more "run off the road" crashes to the right of the carriageways in the crash records, however, this may be a symptom that the vehicle has become the "sacrificial lamb". This may be because most single occupant "run off the road" crashes are on left, however very few of these result in injuries as the left side of vehicle cushions the impact which means there is no need for a police report to be prepared. Thus a major problem relating to these types of crashes is being overlooked in terms of understanding the cause of these crashes and thus "run off the road" to the right has become the focus of road safety programs which have for many years focused on reducing symptoms rather than finding out the cause (i.e. fatigue, avoiding kangaroo, poor handling of the vehicles a tyre blow out etc.). It is likely many of these crashes go unreported by the police yet often it appears that these drivers seek medical treatment in the next 24 hours or so due to severe busing and pain. Hence, the reason why hospital records are now rising and, maybe involve up to twice the number of crashes as those reported by the police. Thus we need to

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[143] How do we advise motorists that are now are entering a urban zone where designers have allowed for a 40% reduction in reaction time i.e. 2 seconds instead of 2.5 seconds based on research that urban drivers are more alert.

[144] Recent ddiscussions with TAC Victoria and their online survey findings indicated that major distraction of drivers were considered to be their own personal thoughts and distraction by other passengers, with mobile phone well down the importance list. It is suggested the drivers may know best and we should listen to what they are telling us rather than honing in on suggestions motorists rate much lower down in priority. Hence we need to move away from popular topics in the media and focus on the empirical evidence in the surveys.

understand all crashes not just the ones where we have records prepared, as it is likely that only about half to one-third of casualty crashes are reported and therefore we miss many of the details relating to the underlying crash cause.[145]

As raised several times during meetings by psychologists, often the drivers mind is elsewhere and one example mentioned was regarding professional truck drivers who are away all week and, often crash in the last few miles or last hour on their way home at the end of the week as their mind suddenly switches from the driving task "as work" to preparing to return home and interacting with their family. Thus their mind is elsewhere with similar symptoms to "**Highway Hypnosis**" and "**Velocitation**" discussed above. Therefore behavioural scientists are critical to unlocking causation of crashes such that we can find cures and hence appropriately defined interviews undertaken by behavioural scientists will ascertain the human elements behind many of these crashes and identify commonalities and new pathways to provide solutions.

12.4 Driver behavioural models

Discussion with behavioural psychologists Dr. Chantel Merkx and her team at RWS Utrecht identified a report titled "A Critical view of Driver Behaviour Models- what do we know, what should we do", (Michon, 1985), as a useful reference and the report states:

"Human mobility is embedded in a social as well as in a technological environment, and ***traffic and transportation issues should be treated in terms of the characteristics of a system in which the human being is only one of the many components, albeit an important one****. The most characteristic feature of the human component in this system is its behaviour as an intelligent if not quite in-fallible problem solver.*

Taking this point of view one may outline a descriptive framework which allows the specification of a number of basic tasks that together constitute the set of relations between people and the environment in which they attempt to satisfy their mobility needs. In this context, it is possible to distinguish four stable levels at which the human being is in systematic interaction with the transport and traffic system as such (Michon, 1976; Michon and Van der Molen, 1976). These levels may be defined by reference to a person's role as an active road user, a transportation consumer, an active social being, and a psycho-biological organism satisfying a number of basic needs, respectively.

The generalized problem-solving task of the driver-qua road user-may be further divided in three levels of skills and control: ***strategical*** *(planning),* ***tactical*** *(manoeuvring), and* ***operational*** *(control) respectively (Michon, 1971, 1979; Janssen, 1979).*

The ***strategical level*** *refer* Figure 45 *below defines the general planning stage of a trip, including the determination of trip goals, route, and modal choice, plus an evaluation of the costs and risks involved. Plans derive further from general considerations about transport and mobility, and also from concomitant factors such as aesthetic satisfaction and comfort.*

At the ***tactical level*** *drivers exercise maneuver control allowing them to negotiate the directly prevailing circumstances. Although largely constrained by the exigencies of the actual situation, maneuvers such as obstacle avoidance, gap acceptance, turning, and overtaking, must meet the criteria derived from the general goals set at the strategical level. Conversely these goals may*

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[145] Although the reference is unknown earlier in my career, Circa 1985, in a presentation by Horman C, Road Traffic Authority Victoria of crashes in Canberra, Australia reveal that "property damage only" crashes provided considerable more insights into crash causation over and above that which was provided by a much lower number of casualty crashes.

occasionally be adapted to fit the outcome of certain maneuvers."

It is an error at the **operational level** (microseconds) where crashes are likely to occur (i.e. errors of judgment enacting maneuvers) which has already been identified as being necessary as part of the strategic or tactical levels that generally result in the crash.

Hence traffic behaviour is a wide-ranging concept. [Knippenberg et al., 1989] include a comprehensive description of traffic behaviour in their Handbook of Social Traffic Engineering [in Dutch: Handboek Sociale Verkeerkunde]. The task of traffic can be better understood when we make a distinction between behavioural levels as follows:

Strategic level

- Transport choice: Will I go out or not? Where to, when?
- Modality choice: Which mode of transport will I choose, will I change at the P&R?
- Route choice: Which route will I choose?

Tactical level

- *Speed choice: How fast am I driving?*
- *Lane choice: In which lane am I driving, will I make a turn, will I merge?*
- *Crossing behaviour: Behaviour at traffic lights, gap acceptance*
- *Overtaking behaviour: Can I overtake?*

Operational level

- *Staying on course: Position in traffic lane*
- *Following: Position with respect to vehicle in front*
- *Speed: Maintaining the desired speed*
- *Measures in the area of traffic management are usually intended to influence one or more levels of behaviour in different ways. To achieve this, traffic measures can have more or less of a mandatory character. They can inform, guide and control.*

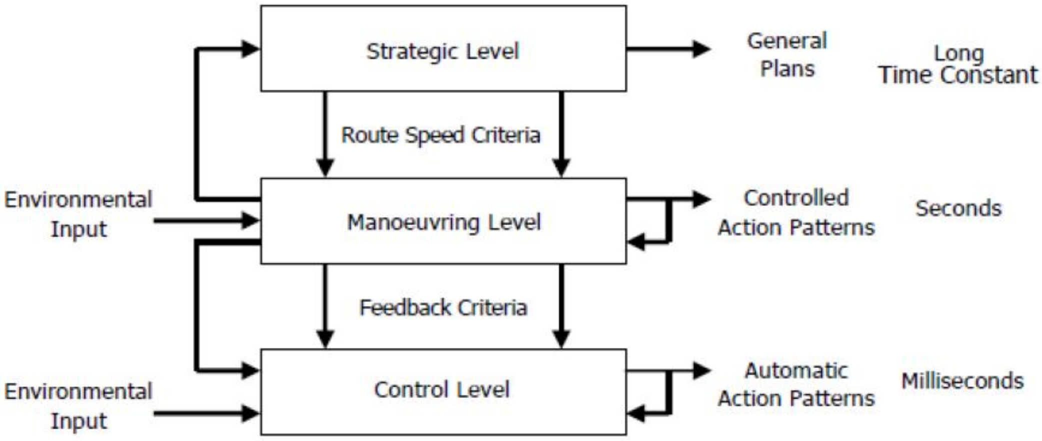


Figure 45 The hierarchical structure of the road user task

From (Figure 45 The hierarchical structure of the road user task), it is suggested that: "*performance is structured at three levels that are comparatively loosely coupled. Internal and external outputs are indicated. When designing and estimating the effects of traffic measures it is important to realise that there is no such thing as 'the average road user'. Unlike the aviation and shipping sectors, roads are used by a varied group of users with a great diversity of characteristics, varying considerably in age and traffic experience. Those users often have their own objectives, they are sometimes in a hurry and sometimes not, and they often interpret and understand rules and messages in an unexpected way. Their capacity to observe is almost unlimited, but not perfect".*

*"They can multi-task, but they still cannot do everything at the same time. They have particular expectations in particular circumstances. In that sense, road users often include people who are susceptible to 'human error'. The traffic system should, therefore, be fail-safe and should be geared to the weakest link. The system should be consistent, uniform and more or less self-explanatory – under all circumstances, including at night and in foggy conditions. [Rijkswaterstaat, 2008] illustrates these characteristics on the basis of Ten Golden Rules see Table 5: Ten Golden Rules Ministry of Transport, Public Works, and Water Management, (*2008 below".

Characteristics and idiosyncrasies of road users	
	Rule 1: Road users are quite selfish
	Rule 2: Road users cannot do everything at the same time
	Rule 3: You can tell road users to do something, but will they actually do it?
How road users view traffic and traffic measures	
	Rule 4: Road users only accept measures that they think are meaningful
How road users react to conditions on the road	
	Rule 5: Road users are full of surprises
	Rule 6: Road users have expectations and behave accordingly
	Rule 7: What happens if the system or the road user goes wrong?
What road users demand from the information that you give them	
	Rule 8: Tell road users what is really important
	Rule 9: Do not confuse road users
The requirements to be met by the information	
	Rule 10: Information must be visible, clear and understandable for road users

Table 6: Ten Golden Rules Ministry of Transport, Public Works, and Water Management, (2008)

12.4.1 Behaviour models need revision due to new understanding of traffic theory

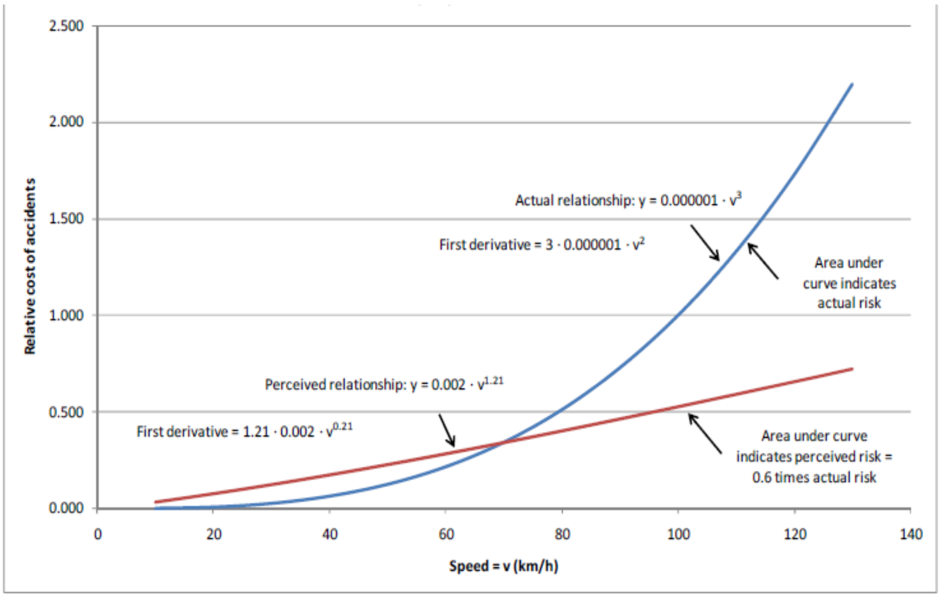
Rule 7 may above may need to be modified to include the element of surprise which introduces uncertainty around how individual road users will respond (i.e. this is somewhat unpredictable).

In light of recent understanding of urban motorway crashes what may be missing is a 4th element of the behavioural levels above being: the "Element of Surprise" as these events cannot be planned for, or easily controlled in the usual sense, as reaction time may be zero and any maneuver which is done under emergency braking and steering the potential for a crash is usually avoided by only a matter of metres. Racing drivers can train for precise and smooth driving reactions under extreme braking conditions, however they are expecting this every time they race, (with a vehicle designed for the task), whereas a motorist may only encounter these circumstances rarely and, most of which prove to be non-events as no crash occurs, as there is little difficulty avoiding a crash. However when shockwaves are present in the traffic flow when driving at moderate speeds (i.e. 70-85km/h), an often unseen wave travelling against the direction of the flow, coming towards the driver from downstream (i.e. a wave of brake lights) typically at speeds of (minus) 18-25km/h. If the motorist cannot see the shockwave coming, a very harsh braking maneuver much greater than usual is required for a vehicle moving at 70-85 km/h when the reduced reaction time is taken into account.

What is becoming clear is the speed that which “Nucleation Events” or “Shockwave Events” physically occur may only be solved by technical solutions, as split-seconds decisions described by Michon above, can now be defined as being truly “split second” where humanities frailties may be the weakest link, as a sudden increase in complexity occurs which often exceeds human capabilities. These complex systems now that they have been identified (i.e. “Black Swan” events), require road designers, traffic engineers, and behavioural scientists to understand the mechanisms involved and work together to identify suitable solutions.

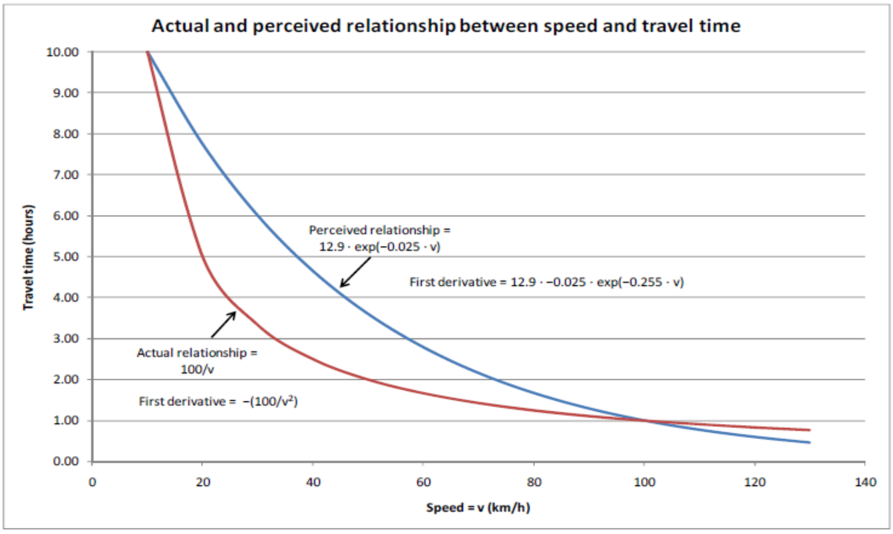
12.5 Drivers are not good at assessing risk

It is clear from research that drivers are not good at assessing changing risk levels when it comes to increasing speed and the cost of an accident, refer (Figure 46 Actual and perceived relationship between speed and the cost of an accident). They also have a poor perception of the relationship between speed and travel time and, tend to travel faster than needed refer (Figure 47 Actual and perceived relationship between speed and travel time). Hence drivers may be risk-taking unknowingly and hence we need to better understand these matters and learn how to educate drivers accordingly.



Source: TØI-report 1034/2009

Figure 46 Actual and perceived relationship between speed and the cost of an accident



Source: TØI-report 1034/2009

Figure 47 Actual and perceived relationship between speed and travel time

12.5.1 Can we teach drivers to read risk for rare events?

We need to understand whether the majority of drivers are able to be taught how to read the emerging traffic conditions and, whether appropriate educational campaigns can be developed on how to drive safely on motorways. However such education programs will need to be sustained like the successful road safety “Drink and Drive” campaigns have over several decades, as it will require changing many long-established driving behaviours, including bad habits, bad attitudes and driver aggression, which has been allowed to occur on our roads over many decades, without being publically named or shamed. Behavioural Scientists in Sweden thought that this type of education had been a major oversight of road safety programs and which needs to be a priority in future programs.

12.6 Training the industry

Psychology and the study of behavioural science relating to road safety and transport are becoming an important part of university training in the European countries visited. This means that students are being trained and equipped for the industry, starting with undergraduates, then masters qualified and ultimately Ph.D. students as is the case at the Technical University of Delft (TU Delft). It was considered that undergraduates who studied one or two subjects in a degree course are inadequately equipped and that a significant period of mentoring by experienced behavioural psychologist’s with considerable research experience[146] is required once psychologists graduate before they begin developing policy, programs or road safety solutions (i.e. practicing on their own).

The actual experience in Australian road agencies is unclear and from observations and discussions, it would seem that officers are often learning on the job and are not always adequately mentored and equipped for the robust analytical behavioural work required to develop effective road safety programs and solutions. In addition, the Netherlands provides specific training to civil and transportation engineers at TU Delft and, workshops and training is provided for local governments

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[146] Mentors need considerable experience like clinical psychologists where they have experience demonstrating that they are able to developed appropriate solutions to problems and show empirical evidence demonstrating successful outcomes. Hence methods can not be a hit or miss process as we are ultimately dealing with human life.

transport professionals including for government transport departments. At TU Delft traffic engineering safety and behavioural science field have been integrated and this also forms a major part of the Netherlands Road Safety Audit training courses. In Europe, Behavioural Science technical handbooks and guidelines are well developed and maturing.

It was suggested that there still remains a lack of a sufficient scientific knowledge and expertise by road safety practitioners in the behavioural science field and, this was emerging as a major issue globally. This aligned with my observations in Australia that often simplistic behaviour modification strategies in the form of marketing campaigns are often deployed by road safety practitioners that do not adequately address all the underlying complexity of the human behavioural elements involved. These attempts often do not reflect the known state of knowledge from research, and/or the complexity of the problems and issues involved.

It is important that we don't practice in this emerging field and operating without significant reference to the available (known) research. This means practitioners need to be very well versed in what is already known and programs must be implemented with "clinical precision". This is too much of an important topic to be learning on the job from scratch and, thus all behavioral modification initiatives need to be clearly demonstrated by empirical evidence (i.e. research already completed) or behavioural scientists need to be actively collecting empirical evidence before they propose and develop any initiatives. Hence it must be observed and measureable with controls groups before strategies and programs are developed. To a large extent the science is emerging but maybe the practice is lagging due to the lack of understanding and structure that needs to be led and nurtured by strong academic leadership, as was the case with traffic engineering and road design 40-50 years ago.

In the Netherlands, as discussed above, behavioural scientists are now working alongside traffic engineers and road designers as part of one design team. Behavioural Scientists (i.e. psychologists), start on road projects at the beginning and are involved in all road design processes to ensure the design is understood by motorists and navigations signage are clear. This program currently involves five psychologists. Thus the role of behavioural psychologists in road design is now taken very seriously from the start of a project with fully qualified psychologists. Prof Marjan Hagenzieker from the Technical University of Delft (TU Delft) highlighted the need to expand the performance metrics such that we start using types of measures that quantify the human factors. Education was considered the best method to minimise human errors which are present in most crashes.

12.7 The need for road safety research to be independent

Finally one of the key points raised in discussions with Dr. Wendy Weijermars, a behavioural scientist at SWOV, at the Ministry of Roads Safety Research, was that research in road safety must be fully independent of policymakers, program developers, and sponsors. Research requires "slow thinking" as discussed above (Daniel Kahneman). When research is independent without the vested influence of sponsors researchers can freely offer advice and education to road agencies without fear or favour, or worrying about where their next job comes from if the client (i.e. policymakers and program sponsors) disagrees with the findings or does not like the advice.

Although not openly admitted for obvious reasons there seems to be some evidence emerging in Australia that sponsors could be compromising road safety research as research bodies are more often than not responding to practitioners direction of what topics should be investigated and, hence researchers are often compromised from carrying out true fundamental empirically based research. Fundamental empirically based research is often not funded as it takes considerably more time to design and deliver the research and thus is often not funded to the extent it is necessary.

The alternate approach which seems to be more comment these days is to have researchers undertaking literature review type research "reading and rewriting" which aligns with the current "fast thinking" (Daniel Kahneman) and the short term directions of sponsoring organisation who are setting the direction, strategies and priorities and wanting fast answers. The problem with "Reading and Rewriting" type research means that often the old bones from a different context (era) get picked over again and again often adding very little new information and/or conclusions particularly when context changes. This type of research often ends with conclusions recommending that more fundamental research is needed and this is rarely taken up by sponsors who want the fast answers.

Often the topics and issues are determined by the current pressing political issues and current news stories and media topics, or sometimes even ways to reduce insurance industry payouts and claims, rather than collecting the fundamental primary field measurements required to identify the underlying cause that precedes crashes in the temporal context in which they occur.

This gradual change in research practice in some Australian States over recent decades can no longer be completely ignored as being a contributor to the gradual rise in crashes. The historical pool of excellent road safety researchers who come up through the system is gradually diluted by the noise and distraction, short-term "fast thinking" delivers. Thus the "slow thinking" that fundamental research requires collecting the raw measurements from the field, which is lacking compared with analysis of traditional crash records which at best only represent a small sample of crashes and, may not collect metrics critical to understanding crash causation or the changing nature of crash risk.

Therefore road safety research must always be independent of agenda and bias, following the evidence revealed solely by the field measurements and with the relevant science(s) applied, and which must be updated when the context changes. For example the context of the Netherlands bicycle fatalities, mobility scooters crashes and highway crashes are all rising whilst fatalities in other transport modes are falling. Researchers speculated that following the global recession of 2009 younger inexperienced drivers are now buying their first cars and need to relearn by gaining more driving experience and hence are crashing more. However we must know the real cause and, this can only come from fundamental research rather than opinion or speculation.

In the Netherlands there was much speculation that other factors are also at play, for example, mobile phones and other in-car devices may be a distraction, or reduced policing or increased speed limits or the current the limits of point to point speed cameras deployment were not extensive enough. In the Netherlands they are genuinely open and admitted they are unsure as evidence from current data sources is not convincing as to what the problems are and hence they do not want to jump to the wrong conclusions without evidence and data (i.e. they need "slow thinking").

The use of mobile phones may well be a human behavioural issues responsible for more FSI crashes in Australia but have we funded the research in Australia to check the phone records of vehicles involved in this year's FSI crashes (i.e. undertaken the fundamental research). Just because we can see more drivers using their phone when stopped at traffic lights in congested traffic does not necessary automatically reveal an association but may well be proven in the future. We however as professionals should not speculate first and develop narratives with the media but rather must provide the scientific evidence first from the crash records? This is quite easy to do, by matching phone record to crashes and an effective control would be whether fatalities and serious injuries are also rising in parts of Australia where there is little or no mobile phone coverage.

13 COMPLEX MECHANISMS REQUIRE NEW APPROACHES AND METHODS OF ANALYSIS

13.1 Context for consideration of road safety analysis

Discussion with Rune Elvik, TOI, Norway suggested that traditional accident “Black Spot” approach is considered no longer effective for analysing crashes and developing solutions for urban motorways and divided highways with increasing levels of higher traffic demand. This statement most likely extends to all roads with moderate to high traffic volumes for at least some portion of the day, week or year and, those roads with considerable increase in the numbers of “Events of Exposure” (e.g. many rural roads) rather than those roads with small annual increases in AADT, as well as at other location experiencing changes to the mix of crash types. Rune Elvik’s research also clearly identifies that when the analysis is undertaken, all known sources of bias need to be considered and corrected for.

These include:

- **Regression to the mean analysis** to acknowledge and correct for random outliers which are usually present in all samples and, that will return a value closer to the mean in the following sample period (i.e. the after study) and, hence need to be adjusted for in **all** road safety studies. Some research reports list excuses for not doing this (e.g. quoting sites were chosen by others); refer Section 19.5 (How do we decide whether a crash cluster is a systematic problem). One Australian paper reviewed in writing this report indicated that “Regression to the Mean Analysis” was not necessary to remove randomness in the sample as the sites investigated were all chosen by the police and the public. Another study indicated it was not necessary due to the five-year sample. Often outlier events are the ones that come to our attention through publicity and hence choosing samples by public popularly and public opinion and arguing against doing it is not good science.

- **Long-term trends,** for example, indicate that motor vehicles are getting safer, medical intervention is improving, telecommunications is reducing the time for medical help, medical advice over the phone from 000 is now almost immediate, telecommunications is almost ubiquitous compared with 15-20 years ago. In addition, road design standards[147] (e.g. wider pavements, sealed shoulders, improved delineation and improved surfacing friction) are all continually improving hence you would expect lower FSI crash numbers, rates or reduced consequences (e.g. minor injury today corresponds to a major injury in the past). Also, certain performance metrics used (e.g. nights spent in the hospital) has seen major reforms with many more patients often discharges early and treated as outpatients in their homes.

- **Changes in traffic volume** such as annual traffic volumes are often only estimated and based on very small samples or estimated based on longer-term trend information and, thus traffic volumes are rarely concise at the AADT level year to year at the specific crash investigation site. Annual estimates of total vehicle travel in Australia are not based on direct measurements like Sweden[148] which regularly records odometer readings of individual vehicles. Australia at the national level reverse calculates travel distances based on assumptions relating to fuel usage and the percentages of vehicles in certain vehicle classes. The traffic volume estimates of State road agencies are generally not accurate enough for

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[147] Although it could be argued that sometimes good road design standards are not being considered leading to uncontrollable risk. It could be argued that some of this higher risk has been offset by better vehicles and better traffic controls

[148] (trafa.se, 2013)

reliable road safety statistical analysis and, often only sampling short periods, (i.e. a week of traffic data), in selected years only. Thus there is a big disconnect on both sides between those who collect traffic data and the many purposes the data is used for and those who use traffic data for their analysis.

- **Confounding of other risk factors** for example, increasing traffic volumes can cause significant increases in traffic density and thus is a confounding risk on urban motorways generally and divided highways particularly at certain times of the day, week or year (i.e. a temporal problem), particularly on roads in growth areas near the margins of the metropolitan cities or leading to and from larger regional centres. It seems like around LOS C, or 90,000 vehicles per day on three or more lane carriageways may be the switch point where motorways operate at a higher crash risk.

13.2 Many Urban motorways crashes are systematic to traffic density

Urban Motorways are generally of a good design standard and this standard is generally homogeneous along a route and, as discussed most crashes may be considered to be spatially random. Even for small clusters of crashes (i.e. less than 5 crashes in 3-5 years), it may be possible that these are just a series of random events, particularly when measured over relatively short time periods and, when locations of these crashes are separated by just 100's of metres where there is generally no obvious road design or maintenance element that would suggest they have a common infrastructure cause. Therefore spatial patterns and groupings of crashes at geographical locations are not always relevant to the understanding the cause(s) of crashes.

However as discussed above in this report, evidence has clearly emerged that crashes are systematic to other attributes, such as with respect to the medium to heavy traffic volumes or unstable traffic conditions where crash risk significantly rises. Medium to heavy traffic conditions usually involves moderately high speeds and variable traffic density conditions and, unstable traffic is usually but not always related to the traffic volume beyond a critical density. Hence the majority of urban motorway crashes are systematic when compared to other factors such as dynamic traffic density as measured by the surrogate "lane occupancy"[149]and to certain types of vehicles (e.g. heavy vehicles, light trucks, motorcycles, utility vehicles and larger four-wheel drive vehicles).

As motorway traffic volumes rise and approach their maximum flow, there is usually a necessary and consequential increase in lane changing activity, which is essential for a motorway to reach it maximum throughput (i.e. required to fill up all the empty road space). When a motorway first begins to slow down or get congested (e.g. slow moving <70km/h) motorists tend to increase their lane changing activity refer (Hall M, 2017). This appears to be in an apparent attempt to gain advantage "to get ahead" so as to reduce their overall travel time, or as often seems to be the case they choose to prepare for their next exit earlier than usual. This occurs because their circumstances have changed, as in heavy and slower conditions they have more time to think and look for opportunities due to the slow progress they are making in the congested traffic stream.[150] This behaviour, in turn, creates more gaps in other lanes that other motorists move into, to gain an advantage in the flow. During heavier flows at higher speeds drivers may perceive there is little advantage for unnecessary lane changes or make lanes changes earlier as they are making a good time, however when speeds are degraded, and as lane speed begins to oscillate (i.e. shockwaves) it often seems easier for many drivers to change lanes as they can pick and choose[151] from a multitude

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[149] refer Figure 21 Relationship btw Lane Occupancy and FSI Crashes - 5min resolution

[150] which may be misguided

[151] humans are opportunists

of small gaps[152] they see in the adjacent lanes.

A recent study of urban motorway crashes indicates that crashes are not random in relation to vehicle type (e.g. heavy vehicles, light trucks, motorcycles, utility vehicles and larger four-wheel-drive vehicles) which represent around 45% of the serious injury crashes and yet may only represent around 15-20% of the traffic volume or exposure.[153] It is not surprising therefore, that many of these vehicles, unlike cars, are less likely to have a wide range of safety equipment such as ESC,[154] emergency braking or blind spot warning equipment, nor do they have the same or even similar stopping distances. Such equipment including the quality of the vehicles braking system should possibly be considered to be essential or standard equipment for driving on congested urban motorways. Thus many urban motorway crashes appear random to spatial considerations and systematic to both the vehicle type[155] and the dynamics of the traffic condition or "Traffic State".[156] This new understanding means we have several new areas of research to undertake and solutions are likely to also come from operational, behavioural changes and, vehicle design and safety applications.

13.3 Drivers are often caught unaware within "Chain Reactions"

The motorway "Traffic State" can change rapidly and motorists generally or at least a large number of motorists cannot anticipate the corresponding sudden change in crash risk as the motorway traffic flow increases in density often quite quickly (i.e. within minutes or seconds). Under these higher risk conditions, it suddenly becomes very difficult for motorists to even prepare for a crash as the density of traffic and vehicle spacing (i.e. headways), is such that stopping or maneuver "sight distance" is severely compromised. Localised and instantaneous "point densities" in lanes increase markedly as safe headways suddenly reduce. For example, high spontaneous point densities occur when vehicles change lanes as they must fit in between the increasingly smaller gap between two closely following vehicles in the receiving lane or when a motorist brakes suddenly as they did not anticipate the motorway would jam up ahead of them.

These mechanisms are not well understood by traffic engineers and road safety researchers and thus the average headway quoted in literature is often in the range 1.5 or 2 seconds which have little meaning in real time traffic operations and, as such values have often only been determined using data from large time intervals (i.e. 15 minute or hourly traffic flows) and do not reflect the instantaneous headways regularly measured in operations (i.e. as low as 0.3 seconds). What is important for road safety is not the average headway but understanding the distribution of headways. From (Figure 23 Typical distributions of headways on an urban motorway), we can see why the crash risk can suddenly become very extreme.

This was further explained by Rune Elvik TOI, as the "reaction time" of the first vehicle near the initial point of congestion forming or the result of a traffic flow disturbance, (i.e. the perturbation caused by a vehicle suddenly braking or changing lanes), is much greater than the "reaction time" of subsequent vehicles following in the traffic stream. Thus the reaction time of maybe the 5th or 10th vehicle might be very small or none at all and, therefore in the current operational regimes crashes sometimes cannot be avoided by hard braking or steering away, particularly if in that particular

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[152] small gaps are easier to negotiate at lower speeds

[153] Currently difficult to determine due to very limited or poor classification and exposure data of some of these vehicle classes where a large 4WD is in the same vehicle class as a car

[154] ESC was made mandatory in Australia for all four wheel drive vehicles from January 2013.

[155] There seems to be significant variability in the braking performance of vehicles of similar types refer (Figure 37 Variations in stopping distance of similar vehicles)

[156] (i.e. "Traffic State" refer Section 16, Understanding The Motorway Crash Problem from Traffic Science)

moment there is no spare road space to maneuver into refer Figure 25. Discussions in Norway indicated approximately 80% of crashes on motorways are "rear end" and "sideswipe" similar to the situation on Australian urban motorways within capital cities and these crash types are typical of the crashes which occur around LOS C conditions and/or in the early stages of the onset of congestion.

13.4 Public education programs need to target over aggressive drivers

Discussions with VTI in Sweden also confirmed this "Chain Reaction" phenomena that are created when the so-called "good driver" (i.e. the 1st vehicle), who was driving too fast and or too close or tailgating. Such drivers initiate the crash sequence by braking too hard or swerving to avoid a problem or when they undertake a sudden lane change maneuver requiring other vehicles to suddenly brake to let them in. These drivers usually get away "Scott Free" often without being aware of the chaos they create behind them in the traffic stream, or ever being identified as being the cause of the crash during any subsequent crash investigation or road safety analysis. The faster more aggressive drivers also have the luxury of adequate "sight distance" and adequate "reaction time" leaving the subsequent vehicles behind in their wake, with little "sight distance" and/or little or no reaction time and, sometimes or though very rarely, a crash event results from this secquence.

VTI Sweden believed public education strategies have not adequately targeted these overly aggressive drivers who believe they are the "good drivers" as they always seem to get away and they are often the drivers who operate just outside the law, a just little over the speed limit and driving just a little too close to other vehicles in front. Often these are the drivers who make rapid lane change maneuvers into small gaps described as "swooping" which trigger many of the dangerous "Events of Exposure". These types of drivers are often the first to complain about slow drivers blocking their lane and impeding their right to travel just a little bit over the speed limit.

The author of this paper has driven in the faster lanes on urban motorways in peak period conditions travelling exactly on the speed limit 100km/h (including correcting for speedometer error in my case 104km/h) yet a queue of traffic will always quickly form behind as if he is a slow driver. As soon as he moves out of the lane the queue disappears quickly into the distance, which is evidence that there is still a substantial group of more aggressive driver behaviours on urban motorways. Urban Motorways requires drivers to have high levels of compliance and collaboration to ensure safe and efficient operation and thus a small number of overly aggressive drivers are problematic.

It was often suggested maybe only 4-5% of motorists have not understood that "speed limits" are only limits, and that there are increased risks of crashes when they travelling too close or at higher speeds than the majority of other drivers. These motorists continue to drive faster even when the majority of responsible drivers have slowed down to a reasonable speed when they encounter increasing traffic volumes and congestion levels, as the drivers have collectively realised an increasing risk of a crash. Such phenomena can be observed virtually every minute of the day just by watching the motorway traffic on an overpass or through a CCTV camera where it is possible to observe that a small group of drivers continue to drive much faster than what would be deemed safe, often tailgating and showing a range of aggressive behaviours.

Maybe we should introduce a concept such as "personal space" when it comes to driving on the road as intruding into another's "personal space" (i.e. tailgating) maybe should be considered to be a rude and unacceptable behaviour. How often do we drive when we can't see the headlights immediate vehicle behind them or the number plate as they are driving too close and are indirectly and rudely saying "get out of my way" or "I'm more important" or "I'm a better driver"? Is it ok to tolerate a vehicle travelling 5km below the "speed limit", like in Germany where trucks are not allowed to overtake if the vehicle they are following is within 10% of the speed limit (i.e. this 72km/h when following a truck which in can do a maximum of 80km/h legally [157])?

Unfortunately, there always seems to remain a few drivers who maintain that the “speed limit” is their legal right no matter what the circumstances and, thus continue to weave their way through heavy traffic to maintain their “rights” even in inclement weather. These drivers are more likely to create the disturbances in the traffic flow (i.e. perturbations or disturbances), that lead to higher crash risk from the sudden braking waves they leave behind them. Behavioural scientists at VTI Sweden therefore, strongly emphasized that: ***“our road safety communications strategies have not targeted these overly aggressive drivers and their behaviours to the same extent and with the same resources that they have tackles other safety issues such as drink driving and speeding”***.

13.5 Motorway merging requires collaboration

Discussions indicated that there is also another regular objection from these over aggressive motorists that promote that other drivers cannot merge properly at motorway entry ramps. Whilst to some extent this is true and possibly 5% of drivers are not so good at merging, however, there are several reasons for this poor merging, which needs to be understood and thought through as follows.

The road traffic law gives the “legal right” to the drivers on the motorway such that they have complete priority over traffic coming in at the entry ramps. Road rules have been established to make driving easy for motorists to comprehend and, to provide legal certainty for enforcement agencies and law courts with regards to the attribution of fault to ensure successful prosecutions or for handing out penalties particularly when there has been a crash. However in practice when moderate to heavy traffic conditions occur two poorly understood issues arise that make it is difficult to merge safely if either of the following traffic conditions arises:

1. there are often no gaps in the traffic on the motorway or gaps of a suitable size for traffic to merge into the motorway at a reasonable speed (i.e. 30-40m gaps or more if larger vehicles are required to merge efficiently). Merging would be easier if motorists on the motorway adjusted their speed to create the necessary gaps to allow ramp traffic to merge. Most drivers actually do the right thing probably about 95% of the time, however, it only takes a few drivers to exercise their “legal right” and not let merging ramp traffic into the motorway and thus cause the motorway flow to break down. Therefore many of the drivers on the entry ramp behave conservatively because from past experience they don’t know whether the next driver on the motorway represents the 95% compliant drivers or the 5% aggressive drivers who in this moment is exercising their “legal right” not to let your vehicle in. Thus motorist are often unable to judge the outcome or are operating from past negative experiences.

2. often the ramp traffic is such that it has become a continuous queue (line) of traffic, with no gaps between vehicles at the bottom of the ramp (i.e. the merging area on the ramp), hence it is almost impossible to merge a large uninterrupted line of vehicles into a heavily trafficked motorway. Hence ramp traffic also needs to be educated to self-regulate themselves by either ramp drivers spacing themselves along the ramp also with 30-40m spacing between vehicles or ramp metering is required to create 30-40m gaps so that vehicles can align themselves with gaps on the motorway.

Typically ramp traffic flows are released often in large platoons from the adjoining arterial road

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[157] vehicles over 3500kg have a maximum speed of 80km/h in Germany

traffic signals and in the absence of ramp metering, large platoons of traffic arrive almost simultaneously at the motorway merge point. Even with ramp metering sometimes drivers do not adequately separate themselves by 30-40m towards the end of the ramp merge area. Some drivers tend to travel together in a bunch which is problematic for motorway merging as the motorway would require a much larger 50-60m gap to accept two vehicles without interrupting the motorway flow. Education will help with regards to these issues (i.e. the need for drivers to collaborate) and this we need to educate the smaller percentage of drivers on what most drivers do based on common sense and courtesy. It may be that the obvious behaviours required have never been effectively explained to drivers in their training and thus “the penny has not yet dropped”.

The law also means that it only takes a few drivers on the motorway to enforce their “legal right” by not backing off and making space to allow for entering traffic, thus they end up breaking down the collaborative system and the motorway slows or stops as a result. Such drivers believe they have no obligation under the law to give-way to merging traffic as they have the legal priority and to them merging traffic is a form of annoyance or nuisance as they have priority. This same group of drivers probably also wonders why the motorway flow keeps breaking down and why their speed is slowed as it takes them 20 minutes longer to get to their destination It might be better for all, including themselves if they could “join the dots” and modify their driving behaviours.

As discussed in Section 6.3.1, driving in heavy traffic conditions involves a high degree of complexity which requires the highest degree of collaborative driving behaviours if the motorways is operate smoothly and safely. Hence behavioural scientists and traffic engineers need to work together to understand the issues involved including working within the laws and developing programs, to educate drivers on the complexity of the mechanisms involved and the dangers associated with motorway merging and, how to safely negotiate merging under heavy traffic conditions. It may be that some motorists on the motorway at times should back off slightly and make a little space for a merging vehicle, or when safe to do so and conditions allow anticipate the problem and move to another lane so that the left motorway lane is able to receive more entering traffic and, enabling easier merging.

Merging on to motorways at a reasonable speed is one of the most difficult driving situations encountered and potentially dangerous and, this is often one of the most talked about issues in the media. It is, therefore, time to focus on this problem with a view to developing credible solutions and appropriate education. This will require behavioural scientists to study both the traffic behaviour and the human dynamics involved in motorway driving. There is a need to stop the talking and find appropriate solutions.

13.5.1 Motorway headway management could ease congestion and save lives

One obvious problem on urban motorways or elsewhere in the road system is that motorists have a tendency to travel too close together (i.e. they tend to flock like sheep). Drivers seem to like catching up to the vehicle in front and forming a bunch by driving too close to one another. There are many psychological reasons why humans behave in this way from aggression, being in a hurry, maintain their advantage within the traffic flow, and as a learned copycat behaviour as everybody else does it. Thus drivers underestimate the increased safety risk of driving too close and do not seem to understand the consequential congestion it very often triggers when there is a sudden braking event which they, in turn, get caught up in and which makes their trip and everybody else’s much longer.

A few motorists seem to have not connected the dots that these types of behaviours bring on the congestion they don’t like much faster and create incidents that further delays their journeys. When vehicles get too close to one another (e.g. tailgating) the natural mechanisms (e.g. empty road space) that keep traffic conditions safe and efficient become degraded when vehicles are weaving, merging and diverging which are all essential elements of motorway operation. These all require reasonable size gaps to occur in the traffic flow to allow ourselves and everybody else to safely change lanes without disrupting the traffic flow. The necessary space required is 40-50m empty road space for every vehicle on the motorway as this space allows adequately for lane changing required for merging, weaving and diverging.

As motorways have progressively become wider with more lanes they have also become less stable due to the increased numbers of necessary lane changes required and, motorways with more lanes require additional empty road space to handle the extra lane change movements. When motorways with additional lanes are controlled by traffic systems they must be operated with lower traffic densities in real time to operate efficiently. When gaps in the traffic are too small say less than 30 - 40 metres between vehicles, lane changing becomes increasing difficult and thus speeds must slow down and additional acceleration and/or braking actions are required as motorists are required speed up or slow down to align their vehicles with a suitably sized gap between vehicles in the other lanes, before they change[158] into another lane to either move towards an exit or to move towards a faster lane.

Hence the spacing between vehicles on motorways known as “headway” is another area that needs an investigation to see how these can be increased with real-time operations (but only when needed)[159]. Unfortunately, most attempts at headway management through signage and lane markings regimes seem to have been less than satisfactory. Although in Germany where it has been legally enforced for heavy vehicles over many years, behaviours seem much more compliant and it has been observed to work well by the author. Again this is another area where the behavioural scientists can assist the traffic engineer and road designer with a way to educate drivers or improve design or operations.

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[158] Often these lane changes are forced on a congested motorway where the gaps are too small and the drivers in the receiving lane have to brake to make additional space

[159] For example a non weave section might be managed differently to a weave section (i.e. managed to a higher density in non weave area)

14 MOTORWAYS SPEED MANAGEMENT FOR EFFICIENT AND SAFE OPERATIONS

The understanding of “Events of Exposure” has important consequences for real-time speed management as part of motorway operations. “Managed Motorways” tools in Melbourne have been reducing “Events of Exposure” now for over 10 years, particularly by reducing traffic density which is one of the key triggers of “Nucleation Events” that trigger many traffic flow breakdown events (i.e. “Shockwave Events”). Figure 48 below shows on the left, the two “Managed Motorways” in Melbourne are performing much better than other currently unmanaged motorways from a safety perspective having their crash rates reduced by more than 30% over the past 5 years[160].

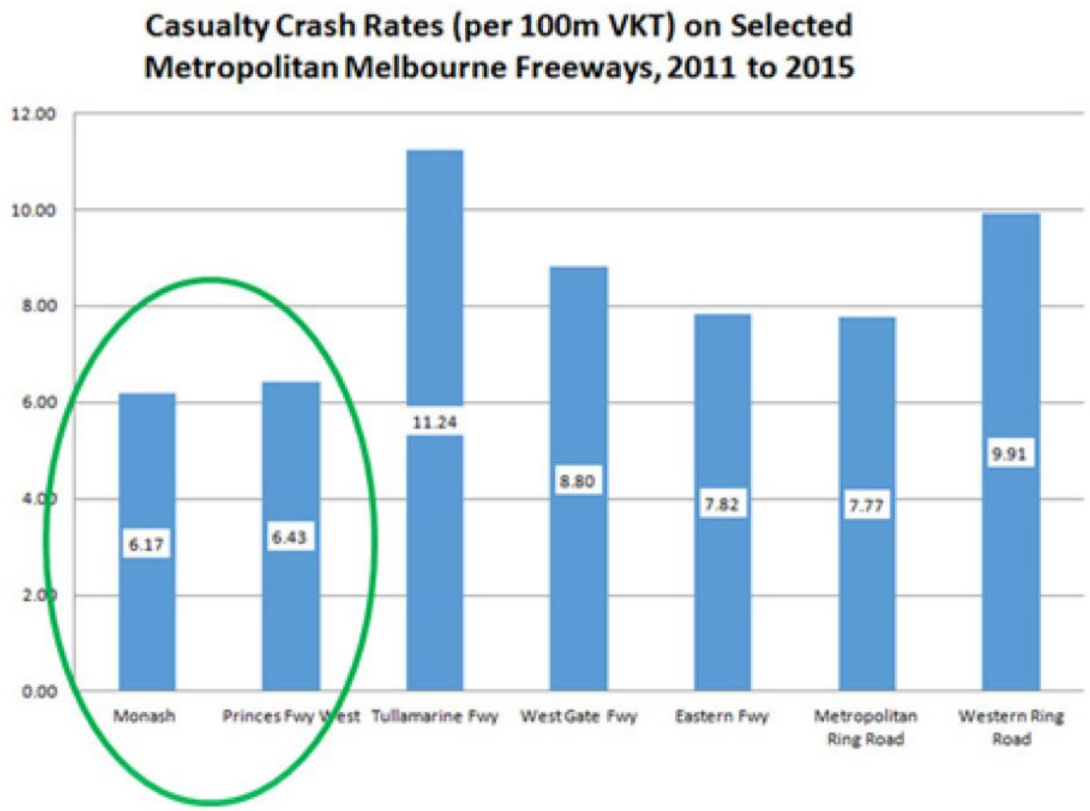

Figure 48 Relative crash rates on Melbourne’s motorways - circle denotes managed motorways

Hence introducing traffic controls in real time can effectively reduce the likelihood of certain types of ”Events of Exposure” occurring and have a positive effect on reducing crashes. The Churchill Fellowship has identified that further improvements are possible and may be relatively easy to achieve by further utilising existing technologies with smarter control systems (i.e. algorithms) that once developed can be duplicated across much of the urban motorway network at very low cost. The following sections provide a high-level explanation of the technical issues involved and the operational improvements that are now deemed necessary and which can be easily achievable with modern traffic control systems.

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[160] A number of the other motorways shown in Figure 48 are currently under construction to be upgraded and converted to “Managed Motorways”.

14.1 How a motorway operates with respect to speed

It is often observed and measured empirically that motorways tend to display a natural differential in speed across carriageway lanes when they are operating at their safest and most efficient. There is commonly a measurable natural differential of both speed and flows across the carriageways lanes which is the outcome of a range of interactions discussed elsewhere in this report. Across a four-lane carriageway, for example, it can be a regularly observed that there is a 20km/h speed differential between the slow lane and the fast lane (i.e. 5-7km/h speed differential occurring between each lane). Motorways have been designed to safely achieve this speed differential (refer Figure 49). This speed differential is necessary as the fast lanes typically carry the higher traffic flows with often up to 500 vehicles per hour more (e.g. 2200 veh/ln/h) and the slower lanes handle the weaving and merging traffic (creating friction) associated with getting vehicles to and from the motorway and often has flows typically in the range of 1500-1700 veh/ln/h.

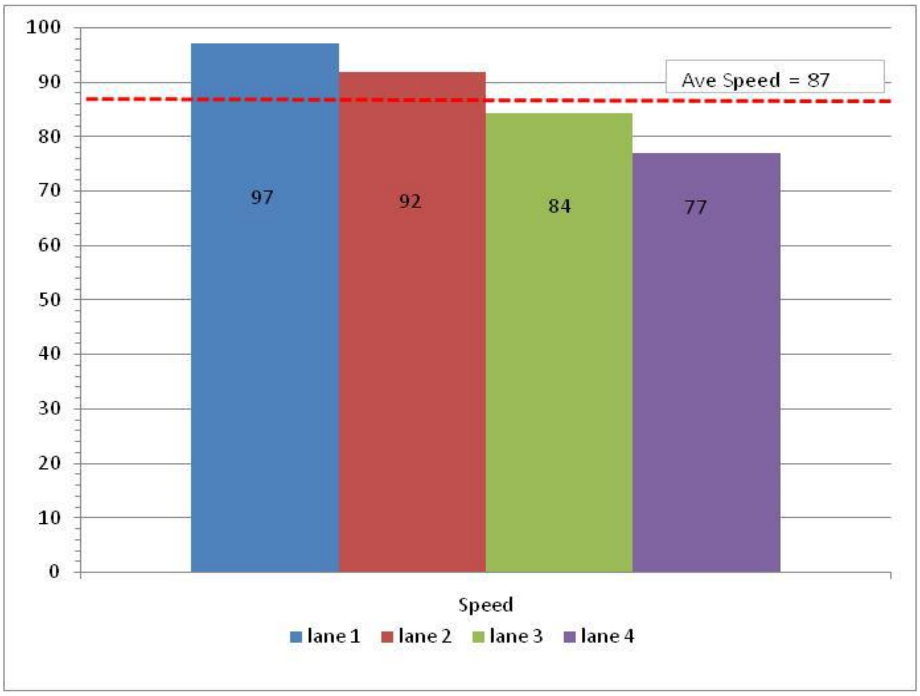

Figure 49 Average lane speeds on a 4 lane motorway operating at capacity

Hence simply lowering speed limits on a motorway at certain times of the day, as has been widely practiced in the past, reduces the motorway's carrying capacity significantly. This, in turn, reduces the motorways efficiency and reliability and, homogenises the traffic flow (Knoop V. D., 2010) by slowing all lanes and consequently increasing their density thus decreasing the spacing between vehicles making lane changing more difficult and potentially more dangerous (i.e. elevates crash risk).

Traffic theory indicates when speeds are reduced both the physical space between vehicles is reduced as well as the time-space between vehicles, making the necessary lane changes associated with weaving, merging and diverging maneuvers much more difficult. Thus the motorway potentially becomes more dangerous as often lane change maneuvers become forced as gaps become smaller and when gaps are small there are the associated increased numbers of "blind spots". A paradox for motorways is that FSI crash risk is elevated when average speeds are considerably lower than the speed limit (i.e. 70-85km/h) combined with increasing and/or variable traffic density levels.

In Figure 49 when the average carriageway speed is 87km/h, reducing the speed limit to 80km/h is likely to shock the motorway and collapse its flow, and thus increase the crash risk. This is another paradox as the intention of the speed reduction might have been to lower the crash risk. However when the average carriageway speed naturally reduces to below 80km/h, (i.e. a further 7km/h reduction) in the above example, it appears it would be safe using a "Smart DVSL System" to reduce the speed limit to 90km/h. Managing speed limits this way has the potential to improve both the safety and efficiency of motorways and thus there are much smarter ways to control speeds. This is explained in more detail below.

Also as stated above it is the faster lanes that carry the much higher traffic flows (which gives motorways their high efficiency), whilst the slower lanes have considerably higher densities due to the "Lane Shear" effect, as all vehicles in the carriageway at some point must pass through these slower lanes to enter and exit the motorway which increases the lane density, (particularly at point locations the extent of which has been historically difficult to measure), thus the slow lanes generally have much lower measured flows but higher turnover of vehicles numbers. If the faster, higher flow lanes are shocked suddenly by a reduction in the speed limit, this has the potential to instantaneously cause a shock to the motorway, as the fast lane volume reduces suddenly and density increases sharply with the higher (current) lane volume having difficulty shedding or dispersing as its capacity is suddenly reduced. This results in an almost instantaneous spillover of vehicles into the other lanes, as there is no longer any advantage in the fast lane, (i.e. inducing unnecessary lane changing and homogenisation of speeds and volumes) (Knoop V. D., 2010). Such behaviour changes can sharply increase crash risk.

14.2 Smarter ways to control speed limits

Researchers and policymakers have often relied on a single historical piece of research relating to a "U shaped" relationship associating differential speed with increased crash numbers. However it would appear from recent research that there seems to be little evidence for such a "U shaped" relationship and rather reductions in "mean speed"[161] is a better indicator of reducing crash risk, refer (Elvik, Speed and Road Accidents - An evaluation of the Power Model). Such conclusions are most likely to be statistically correct when analysis of traffic data is carried out at the macro level with a large number of crashes investigated over many years in many different countries. However macro studies of speed data often miss the micro detail of certain mechanisms that occur in traffic flow for only part of the day or under certain traffic conditions only. These temporal conditions usually have not been identified or are considered not to be important by researchers to include in the analysis. Often this occurs because the micro level of data has not been made available to them or because the microdata (i.e. traffic conditions recorded at <1min intervals) requires significantly more time to understand and to process.

Therefore when looking closer at motorways and divided highways, it may be that these roads have as much as 80% to 90% of the hours of the day or week operating in relatively low volumes and free flow conditions (e.g. densities relating to Levels of Service LOS A and LOS B). Hence the roads included in these studies may only have relatively short periods of the day or week (i.e. proportionately about 10-12%.) in terms of the total hours at higher flows (i.e. peak periods operating at LOS C,D,E and F) for example with only two or three hours a day out of 24hrs. Thus these macro studies focusing on mean speed have not considered the complexity involved which sudden changes in "Traffic States" and flows in heavy traffic conditions.

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[161] A full understanding of Space and Time "mean speed" are needed to inform algorithms as there are considerable differences in the answers and also in the technologies used to collect data (Knoop V. H.)

The percentage of time when motorways or highways operate at the higher LOS C, D, E and F, is increasing and the lower average speed associated with these, are the conditions where most urban motorways now operate for much of the daytime hours. Although the number of hours is still likely to be quite small in comparison to the background 24hrs or 365 days a year annualised measurements. Thus peak hour type conditions have generally not been separately investigated due to their historically small sample size, and if they were studied separately, they may have little impact on macro analysis findings at that time (i.e. 10-20years ago). The current crash problem has been identified a "Black Swan" event because of the increasing demand and increasing complexity from recent motorway widenings and upgrades, create the conditions where crash risk is elevated and thus growth in crash numbers despite crash rates actually falling.

Findings from today's context is also likely to be considerably different from reports prepared just 5 to 10 years ago when traffic demand was much lower[162] and did not trigger the critical conditions for crashes (i.e. the crash thresholds of traffic density of around LOS C or higher, greater than 90,000 veh/day and three or more lanes). We also now know there are two entirely different driving behaviour and operating regimes for LOS A and B, and LOS C, D, E, and F, which requires quite different driver and operational response and solutions as they have quite different crash risk causation phenomena, and a very different mix of crash types, refer (Figure 5, Figure 6 above and Figure 60).

Contemporary traffic flow theory also suggests that some aspects of differential speed may be involved in higher crash risk on urban motorways during the times when the traffic volume and traffic density is increasing, with a commensurate increase in lane changing activity which is required (necessary) to fill up the remaining spare gaps in the carriageway. These are the times when the more alert drivers have already started to slow down and changed their response to match the actual traffic conditions they observe around them. Yet a handful of drivers (outliers) endeavor to maintain a higher, but usually legal speed, including when the risk crash is becoming much higher as "Nucleation Events and "Shockwaves Events" begin to emerge in the traffic flow.

Thus higher speeds, above certain statistical limits (i.e. the 95%ile speed), by a small number of more aggressive drivers (i.e. higher risk accepting drivers), in heavier traffic conditions, is considered problematic as these are the drivers whose vehicles are more likely to trigger "Nucleation Events". This, in turn, elevates crash risk by creating sudden braking events, which occur unexpectedly "out of the blue" and which often create conditions beyond the capability of many drivers, or their willingness to do so. In some cases, drivers do not use the full potential of their vehicle's braking performance, or in other cases, the vehicle has relatively poor braking performance, refer Section 10, (Are Vehicles Safe when Faced with an Emergency Stopping Situation?).

Thus some speed limit intervention under certain traffic conditions seem desirable to clip the higher end of the speed distribution profile and in so doing lower "mean speed", (refer footnote 161), even by as little as 5km/h (i.e. "the Wipe Off Five" campaign). Lowering the mean speed by 5km/h using this method reduces the speed of the faster 5% of drivers generally in the higher volume traffic lanes, by a greater proportion as a 5-10km/h slowing, of these higher numbers of faster vehicles still travelling close to 100km/h, down to 90-95km/h. This will make the road much safer for all motorists, as it reduces the chance of a "Nucleation Events" being activated in the traffic flow which often occurs when the faster vehicles suddenly catch up to the majority of vehicles who are

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[162] It has been found that many data collections systems used on urban motorways (i.e. traffic loops) have disproportional or distorted accuracies for volumes and speeds measured at the higher LOS ranges on multilane motorways (i.e. with 4, 5, 6 lanes or more), due to a number of factors including double counting vehicles doing lane changes and undercounting during congestion events hence there may also be considerable systematic errors in most of the analysis reports using this type of data during peak traffic flow conditions.

travelling a little slower e.g. 5-10km/h slower, or by a higher speed vehicle making an aggressive (i.e. swooping), lane change maneuver. When the speed limit is lowered from 100km/h to 90km/h other motorists already travelling slower are also likely to either adjust their speed slightly downwards or at least would have an increased level of alertness due to the speed limit being physically lowered (and visibly – to alert drivers of increased crash risk). Thus if nothing else, this sends a visible message to drivers that something is changing within the traffic flow so time to wake up, concentrate, be alert and not be distracted.

14.2.1 The science of speed

Understanding from recent studies into road crashes on urban motorways means the next round of incremental improvements in motorway efficiency and safety will come from improved control systems. These systems will seek to optimise the motorway in real time, both for safety and efficiency, and thus the reason for meeting with Professor's Markos Papageorgiou and Ioannis Papamichail, Technical University of Crete, who are well researched and published in this field.

What is required is a Smart Dynamic Speed Limit Systems (SDVSL) where speed limits are reduced as little as 10km/h in small incremental steps in a manner to not reduce capacity or interfere with traffic flows (i.e. breaks down the flow) as previous generations of these systems appear to have done. Speed limit systems have often induced more congestion (refer Figure 50 above), which shows a 20km/h reduction in speed from b=1.0 = 100km/h to b=0.8 =80km/h may reduce capacity of a 4 lane motorway in the order of 10-12% of maximum flow 8000 veh/h (i.e. a theoretically a loss of 800 - 960 veh/h). **At the event of a significant speed drop the capacity reduction is instantaneous as a new bottleneck is created, (**refer Figure 51 Vehicle trajectory showing voids (shown red) created in the flow when speed reductions are introduced**)** which need to be understood, as these voids can possibly be used positively to improve operations and safety for managing major bottlenecks, or can be misused to induced an unwanted bottleneck and thus are likely to exasperate the safety problem by inducing and increasing the duration of congestion.

Figure 50 Generic speed density profile for motorways e.g. b=0.7 = 70km/h

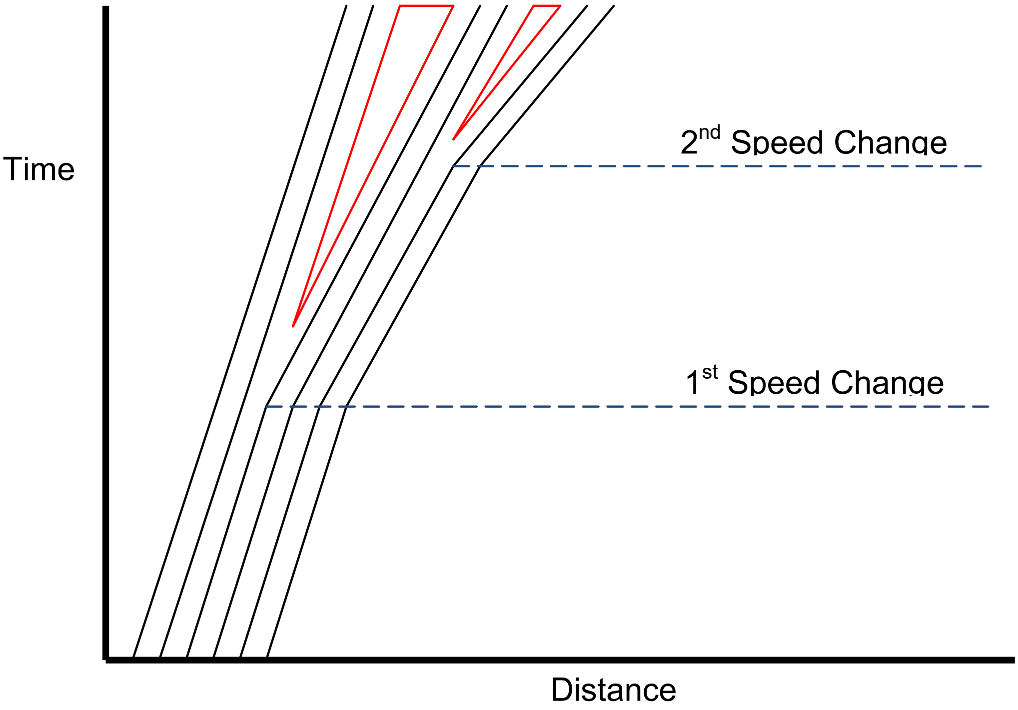

Figure 51 Vehicle trajectory showing voids (red) created when speed reductions are introduced

Hence more scientific and contemporary approaches are required to "manage speeds", on motorways rather than the simplistic approaches of the past, (i.e. "let's lower the speed that should fix the safety problem"), which usually increases the congestion and the crash risk by activating "Events of Exposure" earlier and with much greater intensity and, for much longer periods of time, as such approaches may increase the peak period by 15-30 minutes or more and increase the travel time's of 10,000's[163] of vehicles by 10 to 20 minutes or more, refer (Section 6.3, The scale and nature of motorway demands).

Such historical and still common approaches to reducing speed limits on motorways has been often accompanied by statements "***that it will only take everybody a few minutes longer and hence safety advantage is more important than traffic efficiency***". Such statements can only occur from a limited understanding of traffic theory and road safety crash mechanisms. It requires only a basic understanding of traffic flow theory, to see that if the motorway is suddenly shocked it turns into a chaotic "Traffic State" with its capacity reduced by as much as 20-40%, impacting many kilometres upstream (i.e. often 10-15km). The result will be an increased crash risk and significantly extended period of higher crash risk for many thousands of motorists. In so doing it provide unreliable travel and reduces the productivity[164] of the motorway as a system by up to 50%, (refer Figure 1 Motorway lane occupancy plot showing nucleation events (circled) – a crash precondition), where the shockwaves, (i.e. the red lines), extend for 15km or more.

Thus the few minutes of delay may in result in 10-20 minutes longer travel time for as many 10,000's of vehicles serviced each hour along motorways, (refer Figure 10 Daily profiles of trips on M1

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[163] The M1 motorway in Melbourne has 45,000 vehicles serviced from about 5:30 am to 7pm at night and >60,000veh/h serviced in peak periods Figure 10 Daily profiles of trips on M1 Motorway (15min)

[164] Productivity measured by the product of flow x speed

Motorway (15min)), where between 40,000 and 50,000 trips are serviced in each hour of the daytime hours. What is now known form the traffic data, is that when speed reduces due to congestion or via the lane control or traffic controls, (e.g. changes to speed limits), then lane changing is also likely to suddenly increase, as motorists jockey for some apparent advantage and hence additional “Events of Exposure” are activated. This is another reason to avoid unnecessary speed limit reductions unless it is absolutely necessary to provide for safety and efficiency.

Therefore SDVSL Systems are no longer about slowing motorists down deliberately and suddenly with coarse interventions, but rather supporting the majority motorists (i.e. the 90-95%), who have already realised from the traffic conditions it is safer to travel just a little bit slower, and their speed has already been reduced to around 80km/h. Thus speeds limits may at times be able to be safely reduced to 90km/h, but, only at times when both traffic volumes and traffic densities are high, on the shoulders of, or during peak periods. As discussed above, when both traffic volumes and density are low, differential speed has not been proven to be problematic as there are plenty of gaps in the carriageway for motorists to move freely along the motorway and between the lanes.

Likewise with a SDVSL system the speed limit would rise rapidly as soon as traffic conditions begin to improve. Thus when average speeds began to rise above 80km/h the speed limit should quickly rise back from 90km/h to 100km/h based on a combination of speed, flow and density thresholds (i.e. as measured by lane occupancy). At other times when the motorway has slowed down considerably or stopped (e.g. <50km/h) the speed limit should no longer be left as it currently is at the 100km/h limit, but rather the speed limit should be progressively reduced to around 60 or 70km/h and rise rapidly as soon as the motorway traffic conditions begin to improve. This is because speed limits should not interfere and work against optimising traffic flow and safety outcomes by holding the speed too low and for any longer period than necessary.

Therefore research strongly indicates that smarter use of existing speed management systems by intervening dynamically using SDVSL systems to reduce “mean speeds” by reducing speeds of only the faster drivers in the natural speed distribution has the potential for delivering significant safety benefits to the community. Such approaches should reduce the overall crash risk, during times when very high traffic densities occur, when congested conditions are about to occur as well as during adverse weather events such as damp or wet pavements[165] or foggy or misty conditions when visibility is reduced.

From this new or extended understanding of the science of speed, with respect to both traffic flow and road safety, smart speed intervention is likely to be beneficial on urban motorways where the capability to modify mean speed, refer (footnote 161), using SDVSL systems which utilise existing Variable Speed Limit (VSL) Systems already installed along many urban motorway sections in Australia. Smart DVSL needs to be used strategically and tactically to maintain traffic flow and, reduce the length of congested periods and reduce crash risk by avoiding “Events of Exposure”.

14.3 Implementation of smart dynamic variable speed limit systems

14.3.1 Use of dynamic speed limits integrated with coordinated ramp metering

One of the key areas where crash risk on urban motorways could be further reduced through the use of “Managed Motorway” tools such as “Coordinated Ramp Metering” integrated with SDVSL systems. There is no evidence for the potential to integrate these tools to further reduce ”Events of

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[165] More research is required for hot pavement where pavement friction seems to be very low, potentially a unique a problem for much of Australia

Exposure", by reducing the complexity in the driving task by reducing both speed and moderating the large fluctuations in traffic densities that occur when motorways are left uncontrolled and become chaotic systems.

The mechanisms involved in managing traffic density and managing speeds at critical times are now becoming understood. Discussions with Professor M. Papageorgiou reveal it is possible to optimise a motorway in real time for both traffic flow and road safety. Such systems may also warn motorists using VMS messages of likely deteriorating traffic conditions and intervene to reduce the chance of vehicles arriving too fast at the back of slower moving motorway sections, (i.e. back of queue control) and, which smooth and regulate the supply of vehicles heading towards major bottlenecks.

14.3.2 Driver behaviours are varied when speed limits are reduced

There appears to be emerging evidence in the traffic data that there are some dangerous braking maneuvers when motorways speeds are reduced either dynamically or at fixed speed zone changes (i.e. a permanent reduction from 100km/h to 80km/h). It may be that in the future only 10km/h steps should be used (i.e. introduce a transition step of 90km/h), as the mechanisms to reduce motorways speed suddenly by 20km/h can activate a large range of different driver behaviours. This is particularly evident when speed limits are reduced from the default (maximum) in 20-30km/h steps. This seems to be the current Australian practice during which motorists will usually display a range of individual behaviours which collectively confound the safety problem, and which are likely to increase the crash risk as follows:

- Some drivers will brake very hard which is likely to cause more FSI crashes.[166] This has been learned behaviour described by some motorists who felt they have been unjustly fined in the past and are nervous when regularly passing a speed camera, dropping their speed suddenly which is a known trigger of "Events of Exposure" which may also form secondary crashes,
- Some drivers will back off on the accelerator, gradually slowing down to the new limit, the distance required will depend on the grade of the motorway (i.e. up down or flat),
- Some drivers will only slow down according to the visual conditions[167] and cues they observe or take from a supporting VMS messages posted advising of reason for the speed change (i.e. a crash),
- Some drivers will not slow down as they may not see the first gantry as they are concentrating on the complex traffic conditions (i.e. 2000 lane change/kilometre per hour or reading roadside advertising) or are themselves making a lane-changing maneuver or maybe hidden between or behind a larger vehicle at the first LUMS gantry they pass under[168].

Another problem appears to be with the current enforcement regimes which do not understand motorway conditions or traffic theory for in any one minute the traffic flow in one lane can stop and then start again and under these conditions a driver could momentarily exceed a reduced "speed limit" as they shuffle forward and yet their average speed might only be only 20-30km/h. Yet they may momentarily pass the fixed location speed "safety" camera doing 45km/h and they receive a hefty fine disproportional to the offense, crash risk or any reasonable assessment of the need for enforcement. Under these conditions, motorists are behaving responsibly and driving according to the road conditions as motorists are concentrating on their driving activity in congested conditions

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[166] Evidence for more FSI crashes is emerging at motorway point speed camera sites

[167] Roads should be somewhat self explaining when it comes to speed limit regimes – driver should be advised of reasons via VMS signs

[168] Discussions in the Netherlands highlighted that colour blindness was a possible problem with a fixed red X display for closing lanes and hence they had modified the LED colour to being slightly more orange.

and trying to accommodate the variable conditions they experience. Such driving should not necessarily be considered to be dangerous and nor does it reflect an increased crash risk that can be demonstrated empirically nor does it appear to meet the expectations of the community.

Hence motorists need to be clearly advised and well educated on what is the expected behaviour as it appears some fixed point based safety camera locations on urban motorways may have unwittingly induced some crashes. Thus the issue of SDVSL systems and enforcement need to be reconsidered, particularly in light of Section 14.4 below.

14.4 We have a hidden speeding problem on our urban motorways

While safety cameras focused on catching relatively minor speeding offenses on the motorway, they may well have missed a much greater speeding problem. As there appears to be a more serious underlying speed problem on urban motorways, as compliance with the speed limits does not seem to occur upstream or downstream of the speed cameras locations as evidence from motorways data, as shown in Figure 52 below. This Figure shows excessive speeds were recorded some 5km upstream of a speed camera site on a Melbourne motorway where approximately 3000 vehicles are excessively speeding in every calendar month (i.e. >110km/h in a 100km/h default speed limit zone), with one motorcycle recorded at 240km/h.

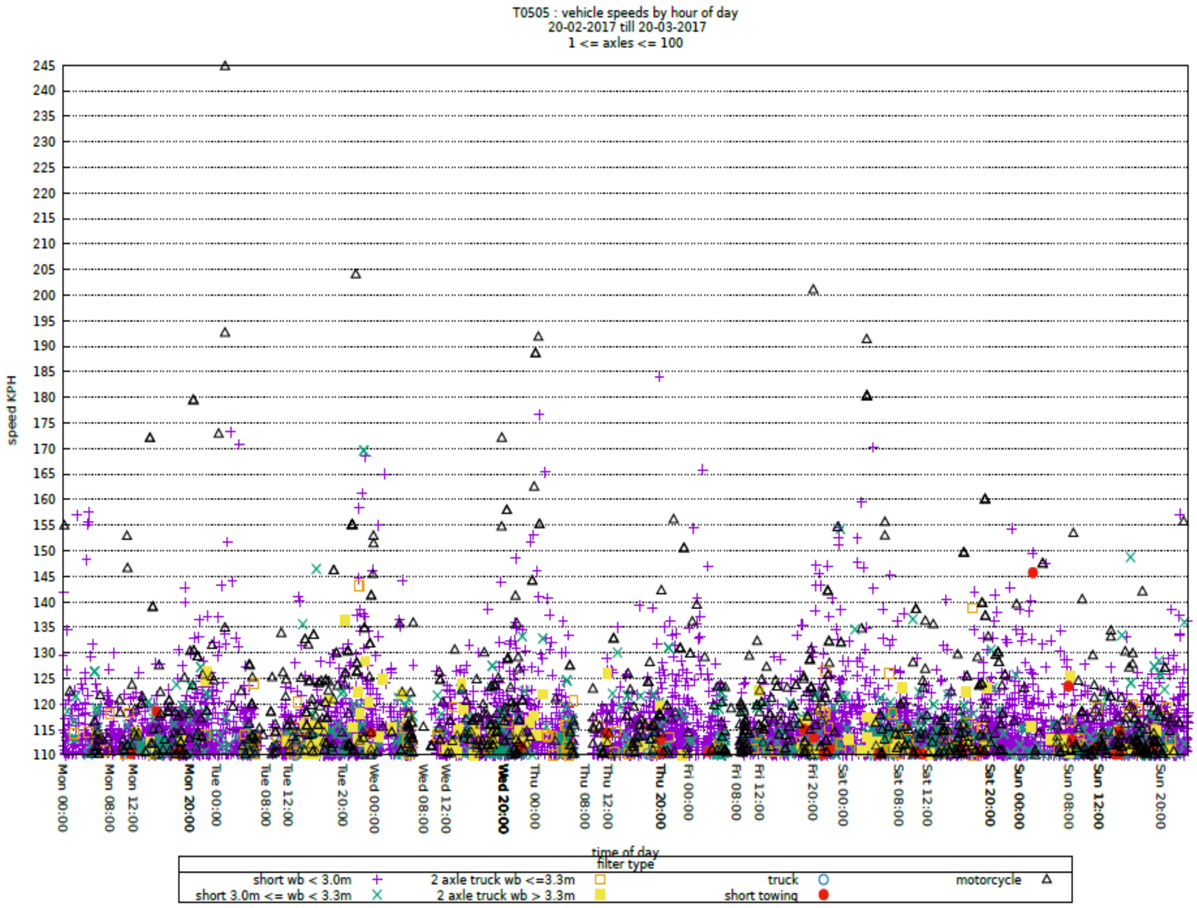

Figure 52 Excessive speed on urban motorways away from fixed-point speed camera locations

All these speeds were recorded in a 1 month period on a single carriageway (at a point location) and the other carriageway (outbound) has a similar number of events (i.e. also 3000 events in a 1 month period). However, it is likely very few of these drivers would have been caught at the camera location as these are the drivers who know where the cameras are located thus have developed a form of “Exposure as Learning” (refer Section 7.4.4) mentality of “once bitten twice shy” (i.e. speed somewhere else).

To apply one of Rune Elvik’s theories mentioned above, motorists learn to modify their driving behaviour when faced with regular “Exposure as Events” as is the case with speed cameras at known (i.e. fixed point) locations, where the behaviour learnt is to “slow down for the camera”. This is the reason why many European countries strongly favour a “multiple point to point” speed enforcement camera regime and were surprised to hear that fixed point cameras were still being used regularly in Australia and, in particular on urban motorways where such complex operational traffic conditions apply. From discussions it seemed that although there has been regular communications and visits between Australian Road Safety agencies, and their counterparts in Europe, that important details of how higher level principles and philosophy actually translate to road design and operational practices have seem to have got lost in transition.[169]

Therefore it is essential to take time out and reconsider both the emerging road safety evidence and our operational objectives to improve outcomes in this area.

Leading edge SDVSL techniques will require discussions with responsible parties as current enforcement regimes are based on a relatively simple understanding of VSL systems and have often been implemented as part of “Lane Control Systems” which are now more widely implemented, and which are primarily used for incident management and maintenance activities. Since there is now more understanding of issues, the current regimes do not appear to be as effective as they might otherwise be, refer (Figure 4 Growth in motorway casualty crashes in Melbourne (2006-2015)). New thinking is urgently required to address shortfalls, in particular, consideration of “multiple point to point” enforcement regime being implemented to eliminate extreme speeds which occur right across the day but is more pronounced during the night time period.

14.4.1 Moving forward

Leading edge SDVSL systems need to be trialed which allow for small variations in speed limits using incremental steps (e.g. 10km/h steps from 100km/ down to 60 km/h), only when necessary in order to smooth flows arriving at motorway choke points and to protect the dangerous back of queue type crashes. As discussed on the Churchill Fellowship this important efficiency and safety measure, (i.e. SDVSL) will potentially require reconsideration by road safety professionals regarding the effectiveness of “fixed point” based speed limit enforcement regimes used on many motorways, given the excessive speeds still being recorded on urban motorways in Australia and their limited ability to work fairly with other traffic management systems (i.e. VSL or SDVSL).

Fixed point safety cameras have compounded the speed problem introducing confusion as some drivers drive faster because they know their speedometer reads lower, while other drivers are not aware of this drive slower, or they drive a little slower to be on the safe side. This is a well-known operational problem and safety problem which has been discussed widely across Australia, particularly as professional heavy vehicles drivers tend to exploit the extra few kilometres per hour. Thus the very low tolerance levels about 1/2 the tolerance levels of Sweden and Norway both of which have an overall better road safety outcomes than Australia, needs to be reconsidered as the speed limit tolerance is less than the accuracy of vehicles’ speedometers which have forced vehicle

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[169] This seems to be also a problem within Australia with a large communication gap between researchers and their understanding of road design and operational practises and practises that do not apply all the findings internationally but tend to be selective and communicate only selected parts of the research.

manufacturers to intentionally lower there readings so they cannot be blamed for the accuracy of the speedometer. We seem to have problem compounding another problem, as safety intentions have confounded with potentially adverse safety outcomes.

Whilst a lower tolerance on the default speed limit (i.e. the maximum speed limit) may still be justified, when SDVSL systems are used to narrow the speed distribution rather than to specifically target or achieve any particular absolute lower speed value. These are new innovative areas that need to be considered. Australian motorways now require new operating regimes which take account of the oscillatory nature of motorway traffic flows, the natural differential lane speeds, which regularly occurs across the carriageway. Smart speed limit systems will have the objective of avoiding certain "Events of Exposure" associated with higher crash risks, such that motorways improved safety and efficiency can be achieved.

14.4.2 Review of enforcement practice needed to support Smart DVSL

The use of advanced Smart DVSL systems is a very complex field of study and future developments require a rethink on how speed enforcement regimes are implemented when speed limits are reduced solely for flow optimisation and safety purposes. This is quite a different situation than when speed limits are reduced for the management of incidents and roadworks activities, which are potentially more dangerous as usually people may be standing or working in the road environment and, vehicles have broken down or crashed vehicles need removal. However, the main uses of SDVSL in the future are likely to be for safety and efficiency and such systems are likely to automatically reduce speeds for incidents well before an operator would intervene as the system would detect the problem almost immediately respond and would appropriately lower the speed limit.

Enforcement regimes on motorways in Europe seem to be more appropriate and effective when "multiple point to point" speed enforcement is primarily used for enforcing the default speed limits only. Australia tends to have mixed practices that need to be reexamined, particularly when a lower than default speed limit is posted. Thus when safety cameras are deemed necessary, we should consider greater use of "multiple point to point" speed enforcement systems together with a review of tolerances applied in oscillating traffic conditions to provide a more sensible outcome for the community. It might be preferable to limit safety camera operations to default speeds limits as is the case in Europe, and in so doing implement contiguous "multiple point to point" sections every 3-4 interchanges, (i.e. spanning every 6-7 kilometres), that work only at the default speed limits 24/7. This will provide much greater opportunity to reduce the apparent excess speeding problem which was the original intent of safety cameras[170]. This also needs effective public education so that driver understand what is being done and why.

It is clear the "Managed Motorway" tools are working with good safety results without the need for excessive enforcement regimes and, hence all well design control systems should modify conditions and driver behaviours with minimal need for enforcement. Enforcement systems when necessary should be considered to compliment appropriate and good road design and operational regimes and never be used to fix a known safety problem. They should not be considered as short-term safety technique to fix an obvious poor road design or operational problem. Such serious problems, when identified, need to be corrected as soon as possible with appropriate infrastructure improvement treatments.

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[170] Some operational practices make it hard to identify if the original intent of safety cameras has been understood.

It is expected that the safety benefits of SDVSL systems will exceed the current benefits of safety cameras on urban motorways as it will regularly intervene by lower mean speeds by reducing the higher speed vehicles within the distribution of speeds thus reducing ”Events of Exposure” when certain critical crash pre-conditions occur. Casualty crash numbers rise when average speeds are just 70 - 85km/h and thus we need to intervene with SDVSL and Ramp Metering systems that collectively target the crash mechanisms discussed in this report.

The following Table 6 Indicative additional benefits of a Smart DVSL with “multiple point to point” speed camera regime c.f. current regimes). The table provides a high-level assessment of how current fixed point safety cameras could be improved to achieve increased road safety outcomes.

Enforcement Regime/ Performance Outcomes	**A. Existing** **Fixed Point Enforcement on all variable speed ranges**	**B. Future** **Fixed Point Enforcement on all speed ranges with Smart DVSL**	**C. Future**[171] **No enforcement Smart DVSL**	**D. Future** **“Multiple Point to Point” Enforcement with Smart DVSL with Enforcement on all speed ranges**	**E. Future** **“Multiple Point to Point” Enforcement with Smart DVSL with Default Speed Enforcement only**
Addresses current extreme speeding problem	Low – see evidence above	Low – see evidence above	Low	High	High
High levels of Community Acceptance	Low[172]	Low	Moderate	Moderate [173]	High
Addresses current crash risk problems	Low [174] FSI crash numbers rising 40% over 10 yrs	Moderate	Moderate	High but difficult to achieve technically	High
Speed enforcement clearly linked to Safety outcomes	Low[175] when operational rules restrict SDVSL	Low	Not Applicable	High	High
Reduces critical “Events of Exposure” i.e. Crash Risk	Low[176] No evidence	High	High	High	High

Table 7 Indicative additional benefits of a Smart DVSL with “multiple point to point” speed camera regime c.f. current regimes

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[171] Sections of 2-3 interchanges

[172] due to large fines for minor discretions e.g. 45km/h in a 40km/h zone or when insufficient time given to all subsequence motorists arriving – not understood as fines are not empirically proportional to safety risk

[173] unless increased enforcement tolerance on fines

[174] as motorway crash numbers are increasing

[175] Unclear as it has assumed most FSI crashes occurs because of higher speeds which is now in doubt i.e. most occur in 70-85km/h speeds, and in its currently implementation, complex operational rules to ensure enforcement have been a barrier to smarter use of DVSL as it makes traffic operations inefficient resulting in poor LUMS operations and unnecessary delays to motorists

[176] Evidence unclear on urban motorways - some evidence of increased FSI risk

Therefore we must work together with those responsible for enforcement regimes to find better ways to improve our methods in light of the findings of this report. Because of the difficulty in the past finding a balanced operational position, speeds limits have unfortunately been left at the default speed limit, i.e. 100km/h, for much higher than they should be to provide safe and efficient outcomes for the community. This is because it is considered to be not appropriate to introduce a new system that might be inherently unfair. Some current speed camera installation requirements on motorways with VSL are restrictive on safer traffic and efficient operations and requirements are often imposed to avoid legal challenges (i.e. defining the minimum number of gantries to display the same speed limit before the camera site to ensure high levels of enforcement) rather than focusing on the mechanisms that will make the motorway safer and enabling traffic flow to be efficient. If we are going to achieve safer outcomes we need to apply smart tools, with this new understanding and develop new operations regimes which are both credible and seen to be credible to the community.

14.4.3 Further considerations

Using speed limits to manage safety and provide efficient operation of the motorway is a relatively new approach and the safety benefits are likely to be much higher than the current Variable Speed Limit (VSL) System approaches. Consideration needs to be given to the tolerances on speed limits that reflect actual traffic patterns on motorways and the natural differential lane speeds and the oscillating nature of flows and speeds between lanes. Also what needs to be considered is the workload on motorists when some 2000 necessary lane changes per hour for each kilometre of roadway occur in heavy traffic conditions.

Enforcement regimes need to take account of multiple consecutive speed zones and the transitioning times required, not just for the first vehicles arriving at the effected gantries, but also for all subsequent vehicles travelling along the motorway who continue to arrive at the slower speed limit zone. The problem of subsequent vehicles arriving at the speed camera zone does not seem to have been taken into account in many current enforcement regimes. Therefore, it is not just the first vehicles arriving at the speed camera that need to be taken into account when selecting a grace period for enforcement to switch in after the speed limit is lowered, and required for all subsequent vehicles arriving at that section. This is another reason why “multiple point to point” speed enforcement is a much better way to enforce and change driving behaviours, although some research and development is required to make this work with SDVSL systems unless Option E in Table 6 Indicative additional benefits of a Smart DVSL with “multiple point to point” speed camera regime c.f. current regimes) is adopted.

If motorists drop speed too quickly on motorways this can induce both primary and secondary crashes by introducing “Events of Exposure” that increase crash risk. Hence the time lag for enforcement regimes to switch-in should not be subjective but rather based on the actual time it takes to slow down a motorway carriageway safely. Just like when water hammer occurs in a pipe when a tap is turned off too quickly so is the case in motorways where sudden braking of 200-300 vehicles induces perturbations in the traffic flow on a massive scale that can cause both primary and secondary crashes causing the crash risk rises sharply. Hence the time taken to slow down a motorway carriageway from say 100km to say 40km/h safely needs to be measured statistically (e.g. used at least 30-day samples taken at many locations under heavy traffic conditions[177]. This data

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[177] It takes a considerable distance of motorway to slow down the average speed on a motorway safely, for example, a 4 lane motorway carrying the equivalent hourly flow 120-160 veh/min slowing down from 100km to 80 km/h safely assuming the speed limit gantries are in the perfect position for the drivers to see and the grade of the road is level and the pavement is dry, refer Figure 18 One-minute flows typically represent 120-160 vehicles. At 100km/h a vehicle travels 1km in 36 seconds and hence assuming they may not see the first gantry a minimum of 2 gantries or at least 1km of travel distance would be required to slow down without the need for suddenly braking

must form the basis for all enforcement decisions rather than be based on subjective opinions by officers as to what is a reasonable delay before enforcement commences. The degree of complexity involved is why European countries do not enforce reduced speed limits but rather treat the reduced speeds as advisory. The management of incidents and motorway optimisation may ultimately need to be treated differently.

Since most motorists intuitively drive to conditions, if the visual road conditions seem okay for drivers to travel at a higher speed when they are faced with a speed limit reduction, the driver will naturally reduce their speed slower. Therefore unless there is a clear safety reason for the speed reduction, motorists should be warned with an appropriate VMS message as to the reason for the speed reductions. This is because motorists need to be advised of conditions up ahead as per the Sweden and Netherlands road safety approaches particularly when major changes are made to speed limit regimes and the road infrastructure and traffic conditions don't provide consistent cues for drivers.

Finally, Rune Elvik's paper titled "The power model on the relationship between speed limits and road safety" refer Figure 46 and Figure 47 in Section 10.8 indicates that motorists grossly underestimate the perception of crash risk and consequences of injury or fatality when confronted with a dangerous situation whilst driving. Therefore intervening regularly with lower speed limits at times when the research data indicates the crash risk is high, seem like a logical path to avoiding crashes or reducing impact speeds should they occur. This being the intent using a Smart DVSL system.

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events e.g. creation of water hammer in pipes. Historically in traffic engineering there has been a science around the 85th percentile values in determining traffic related design parameters, hence empirical measurements are required taking account of the proportion of heavy vehicles and the continuous arrival at the changed speed zone by all subsequent vehicles. In the absence of empirical data very conservative values must be chosen. It would be easier to create more 3-4 interchange "multiple point to point" speed zones and then based on probability, most sections will be enforceable most of the time at the default speed limit rather than endeavouring to over complicate things and enforce with a dynamic system where the current fines do not align with the crash risk.

15 DOES THE SAFE SYSTEM HAVE SHORTCOMINGS WHEN IT COMES TO SPEED?

Many discussions were held during the Churchill Fellowship on why do we continue to sell fast vehicles, (i.e. the "loaded gun"), to consumers in an era where it would cost virtually nothing to limit speeds of all new vehicles to some more reasonable speed limit in line with our Australian road safety regulations and declared maximum speed limits i.e. 110 km/h – 130km/h in Australian States and Territories. Australian vehicles are only crash tested at maximum speeds of 64km/h[178] yet many have the capability to travel at speeds more than 3 times higher. Such a large gap in safety logic may not even pass the "Pub Test" in Australia. **It should be noted that regulating the maximum speed of vehicles is not related to the power of vehicles, nor is it related to reducing the safety of overtaking maneuvers, as these can be accommodated in the modern vehicle fleet by having an automatic override to allow for short 30 - 60-second overtaking maneuvers**.

Discussions with world-leading road safety experts on why we continue to sell consumers, fast vehicle, some of which we know will be driven by people without the necessary skills and capabilities to operate vehicles at that level including those who are immature, irresponsible and sometimes even criminals. Typical responses centered around the vehicle somehow being a symbolic expression of our society's freedoms and, thus limiting the speed of vehicles to some more realistic and reasonable level would somehow affect those personal freedoms. Thus at what speed are those personal freedoms impacted (i.e. 250km/h, 200km/h or 150km/h) when someone else crashes into you? At what speed do we allow our personal safety to be taken away at the hand of others?

These comments on society's freedoms were surprising given these safety experts all worked in road safety fields and promoted a "safe system approach", yet the thing that moves fastest and injures and kills people when it crashes was not strongly within their sights or included in their strategies. Yet "safe vehicles", "safe speeds" and "safe drivers" are three of the pillars of the safe system approach yet the ability for drivers and their vehicles to drive at excessive speed is not considered important or was this driven by other influences as discussed below. Also safe infrastructure has not been designed to deal with excessive speed (i.e. safety barriers).

Further discussions revealed the issue was of a higher social order,[179] a topic you don't talk about, like the line from "Fawlty Towers", "Don't mention the war" or "don't poke the bear" or "it's in the too hard basket" due to the degree of difficulty arguing for change. However, it no longer makes sense to talk about a "safe system" when the system has major "not talked about" shortcomings or one of the pillars is being substantially ignored.

The data presented in (Figure 53 Excessive speed on urban motorways away from fixed-point speed camera locations) above for the Monash Freeway in Melbourne shows we still have a significant speeding problem on Australian urban motorways with approximately three thousand vehicles each month travelling between 10km/h and 140km/h above the speed limit with some vehicles being seen to be racing above 160km/h and one motorcycle recorded at 240km/h in 100km/h speed zone. The current maximum speed recorded during a recent trial was 264km/h. Evidence suggests this may be a bigger problem on rural roads where the risk of being caught is much lower. We should no longer talk about the "safe system" and continue to avoid discussions about the lack of control over the vehicle's maximum speeds.

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[178] ANCAP crash test speeds represent the higher end of real-world crash speeds. For example, the frontal offset crash test is conducted at 64km/h. From real-world (US) data, more than half of all fatalities to seat-belt-wearing drivers in frontal crashes occur at impact speeds under 55km/h.

[179] This was code for being political (i.e. convincing the community, governments and the vehicle industry)

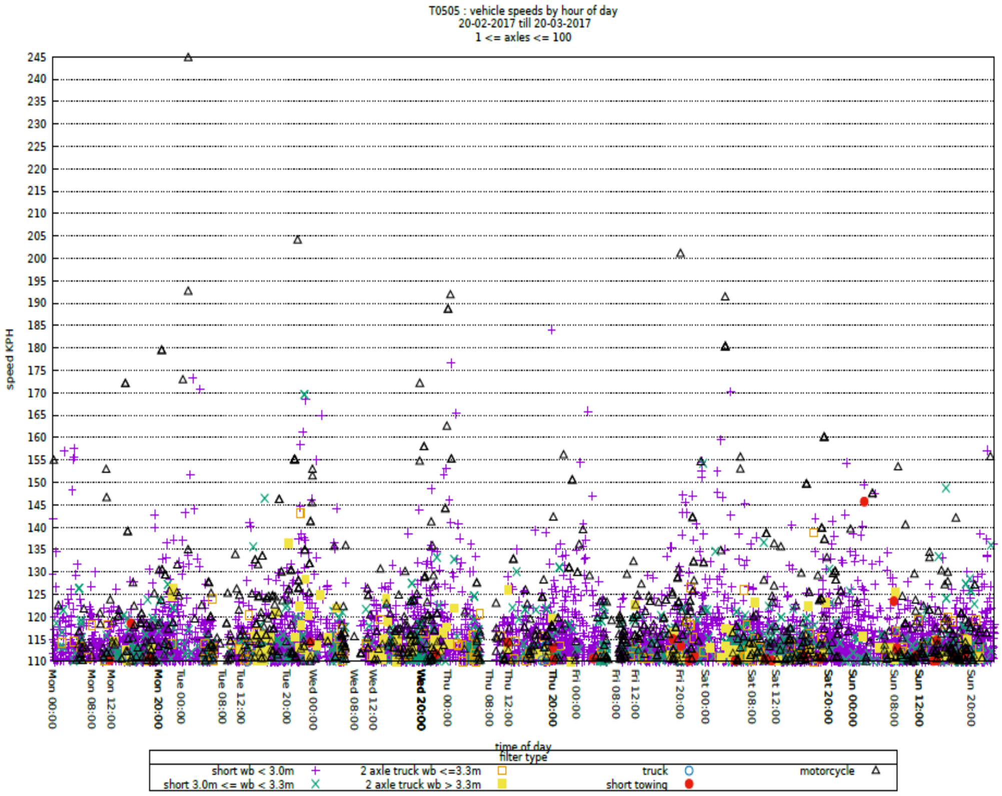

Figure 53 Excessive speed on urban motorways away from fixed-point speed camera locations

We regularly hear "news bulletins" about a stolen car and a police chase in our capital cities sometimes it seems to be almost to be a daily event. Since very few people speak out about the speed of vehicles is this is something our society enjoys seeing on the news, or has been accepted as being normal and okay without any community outrage and/or, is considered just a routine part of the police's job description? We also regularly hear the police spokesperson, politicians, road safety professionals and "talk back" radio hosts complain about there being a speeding problem, yet there is a common reluctance to speak up and intervene on the most obvious component of the "Safe System". Several questions need to be asked and answered by the road safety community being:

- Should we simply limit the speed of vehicles at the source to a more reasonable speed limit (i.e. 140km/h)?[180]

- What is a reasonable maximum speed for vehicles[181] to be limited should be opened up for discussion and public debate?

15.1.1 The road less travelled usually has benefit

While it is acknowledged that limiting the maximum speed of vehicles might be a very hard to introduce quickly, however, over time this can be achieved quite easily and painlessly. All that is needed is a long-term implementation strategy similar to other road safety strategies in the past.

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[180] a suggestion to initiate discussion

[181] Speed limited vehicles would still be able to drive at unsafe speeds on certain roads and thus in the future technology might also limit the speed of vehicles based on locality or road type.

Firstly we could consider offering positive incentives for new vehicles which voluntary are speed limited (i.e. reduced registration and stamp duty fees) and, secondly we could mandate that all repeat speeding offenders must have speed limiters installed on their vehicles before their licenses are returned and, which would be monitored for ongoing compliance.

Currently, in Australia we crush "Hoon" vehicles and install alcohol locks and hence over time just like with the introduction of seat belts in 1970 we can change the community attitudes away from for the need for buying fast vehicles for use as road transport on the public road network. If we start by offering choices vehicle manufacturers will respond and just like they did with ANCAP and it will be accepted over time by the industry. ANCAP could even consider providing additional safety points for vehicles equipped with permanent speed limiters. We could go further by mandating speed limiting as one of the criteria to receive a 5-star vehicle safety rating.

With the high cost of road crashes in Australia being in the order of $30B annually, it would be a sound investment paying some small amount of $M's per annum encouraging those purchasing the 1.3M new vehicles each year, by offering reduced taxes and stamp duty fees for each new vehicle which is speed limited, or consider paying for current vehicles to have a suitable devices retrospectively installed. We must break the connection between road transport and the need for road vehicles to be designed for a fast top speed. Have we got "what it takes" to "make the break" and again be the global leader in road safety as vehicles speed is the seat belt issue of 1970? We may have gone almost as far as we can without further breakthroughs in vehicles design and material science in our ability to protect vehicle occupants in a crash. Therefore it is a simple matter of understanding physics that the faster you travel the faster you hit and thus limiting maximum speeds makes considerable sense.

15.1.2 Limiting the speed of all vehicles safely has been possible for 30 years

The following section shows that reducing the speed of vehicles can be easily achieved as the systems already exist. In the case of Japan it has been in place now for three decades, however, they may have set the bar too high (i.e. 180km/h), refer (Wiki, 2017).

*"**In 1988, cars for the Japanese domestic market had cars which were limited by voluntary self-restraints among manufacturers to 280 horsepower (PS) (276 hp) and a top speed of 180 km/h (111.8 mph)**, limits imposed by the Japan Automobile Manufacturers Association (JAMA) for safety. The horsepower limit was lifted in 2004 but the speed limit of 180 km/h (111.8 mph) remains in effect. **Many Japanese cars for the domestic markets have speedometers that register speed only up to 180 km/h (111.8 mph) (certain Nissans go only up to 190 km/h)**.*

In Germany trucks over 3,500 kg[182] are required to have a built-in speed limiter for a maximum speed of 90 km/h (56 mph), and buses for a maximum speed of 100 km/h (62 mph). *There are a few exceptions for army, police, fire brigade or scientific purposes.*

*BMW, Mercedes and others have entered into a gentlemen's agreement to a limit of 250 km/h (155 mph), but may 'unhook' their speed limited cars in Europe, and **Mercedes will provide some vehicles in the USA without limiters for an additional price**. There are also third-party companies who will re-flash vehicle computers with new software which will remove the speed limits and improve overall performance.* This is something to legislate against and have very high penalties for tampering. [183]

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[182] In Australia 3500kg is the weight of many vehicles (i.e. a large 4WD vehicles towing a caravan or trailer)

[183] Currently some manufacturers offer an option to remove speed limiters for a price (e.g. VW). Which need to be reviewed, discouraged

Many small and medium-sized commercial vehicles are now routinely fitted with speed limiters as a manufacturer option, with a mind towards reducing fuel bills, maintenance costs and insurance premiums, as well as discouraging employees from abusing company vehicles, attracting speeding fines and attracting bad publicity. ***These limiters are set somewhat lower than for sports cars, typically at 56, 62, 68 or 70 mph (90, 100, 109 or 113 km/h) in the UK, with options for 75 and 81 km/h (47 and 50 mph) listed in countries where these speeds are legal****.*

Often the fitting of a limiter is combined with a small warning sticker on the rear of the vehicle, stating its maximum speed, to discourage drivers who may themselves be delayed by having to follow it from tailgating or other aggressive driving intended to intimidate the lead driver into accelerating.

In the Netherlands and UK mopeds are speed limited to 40 and 45km/h. The legal definition of a moped in the United Kingdom was revised in 1977 to include a maximum design speed of 30 mph (48 km/h). This was further revised to 50 km/h (31 mph) in the 1990s, then 45 km/h (28 mph) in the late 2000s to fall in line with unified European Union licensing regulations.

After years in Australia promoting “Speed Kills” and if speeding is still deemed a serious road safety problem then our governments must meet with vehicle manufacturers to install OEM speed limiters and modified speedometers (e.g. maximum speed display i.e. 140km/h) fitted as a standard feature. As discussed above Japan has speed limited vehicles to 180km/h for many years and some German vehicles are speed limited to 240km/h so the technology currently exists.

Just as Australia did with the seat belt in 1970 we must now control speed limits at the source and one day we just might not have the headlines of police being involved in unnecessary high-speed chases which puts the community at risk and which keeps the road toll higher than it needs to be. Our headlines tells us that “Speed Kills” yet we continue to sell the “loaded gun” that provides means and the temptation to travel at excess speeds[184]. As casualty crash rates are again rising across Australia “it is time” to act some 47 years after we mandated the seat belt.

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and possibly legislated against.

[184] It was suggest that vehicles should operate with defined speed ranges on motorways too slow can be as dangerous as too fast under certain operating conditions.

16 UNDERSTANDING THE MOTORWAY CRASH PROBLEM FROM TRAFFIC SCIENCE

Traffic flow on urban motorways at times is inherently unstable meaning that when the motorway begins to fill up to the traffic carrying capacity, the road efficiency can decrease suddenly (i.e. flows decrease in less than 1 min by as much as 20-50%) rapidly changing traffic conditions which can be inherently dangerous for motorists. It only takes a small disturbance in the flow to trigger a change in "Traffic State" which can occur even in what was traditionally considered to be quite low traffic flow and traffic densities (i.e. around LOS C <16 veh/km/ln). Many laypersons and unfortunately many traffic practitioners assume the more traffic you get onto the motorway the more vehicle traffic it carries. This is far from the accurate as when a motorway is overloaded the flow collapses and degrades into a car park with a commensurate increase in the crash risk which progressively degrades the motorway productivity.[185]

Historically the quality of traffic flow has not been linked by traffic road safety researchers or practitioners to the "chance of failure" where the failure creates an inherently dangerous "Traffic State" as shown by recent analyses linking crashes to "Traffic States". Whilst some historical research shows that motorway crashes in congested conditions might not be as serious, (I. Potts, 2015) this is clearly not the case in Victoria[186] where analysis of actual traffic conditions at the time of the crash has been undertaken. The research also shows that more vehicles and people are involved in urban motorway FSI crashes. A recent study shows both the pre-congestion and post congestion periods with moderate to high traffic volumes together with moderate (i.e. 70-85km/h) speed conditions and the initial stages of congestion (i.e. High LOS E and Low LOS F values) cause the most FSI crashes.

From research and published literature there also appears to be little acknowledgement amongst road safety experts that some of the Intelligent Transport Systems (ITS) and "Managed Motorway" initiatives are making solid inroads into reducing crashes i.e. Melbourne's first "Managed Motorway" project on the Monash Freeway resulted in a 31% reduction serious injuries and fatalities when measured five years after opening (Gaffney J, Lam P, Somers A, Boddington K, Johnston D , 2015) refer Figure 57 Comparison of crash rates on Melbourne's motorways btw 2011 and 2015.

It is now possible to show that the crash rates on motorways can be directly correlated to both the pre-congestion and congested traffic conditions, where there are higher distributions of vehicle speeds as the motorway approaches capacity and when queuing is about to begin or forming in at least one carriageway lane. Works by (Oh, 2000), (Alsalhi R, Dixit V, 2015) and (Marchesini P, Weijermars W, 2010) linking the crash likelihood to large speed differences between and within lanes. These are the conditions that "Managed Motorways" target. Another quotation from an important study by (Yeo H, Jang K, Skabardonis A, Kang S, 2014) relating crashes to "Traffic States" is as follows:

"Freeway traffic accidents are complicated events that are influenced by multiple factors including roadway geometry, drivers' behaviour, traffic conditions and environmental factors. The influence of those factors on traffic crashes cannot be fully unveiled without detailed information not only on the crash itself but also on its surrounding circumstances."

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[185] Productivity of a motorway equals the product of speed x flow

[186] This is only true when motorways are approaching gridlock or where average speeds are typically below 30km/h which is not the case when most congestion related crashes occur i.e. 40-60km/h. This highest FSI crash risk occurs when speeds are 70-85km/h.

16.1 Chance of traffic flow failure

In the German HBS 2015, for example, the capacity of a 3 lane Autobahn is 5700 veh/h or 1900 veh/h/ln. The value of 1900 veh/h/ln is significantly lower than most Australian or international traffic engineers and road design practitioners are using from guides such as the USA Highway Capacity Manual (US HCM). However as shown in (Figure 54 Probability of flow breakdown on a 4 lane motorway 2000 veh/h/ln or 8000veh/h per carriageway would represent approximately 50% chance of failure (i.e. flow breakdown, in any 15 minute period), being the point when congestion sets in when the motorway reaches this value. The USA HCM adopts much higher 2100-2300 veh/h/ln which are likely therefore to represent a much greater than 50% chance of failure in any 15min period. Hence the question must be asked what level of "Quality of Flow" is acceptable when determining capacity values for motorways[187] and, is road safety a key consideration for setting these values?

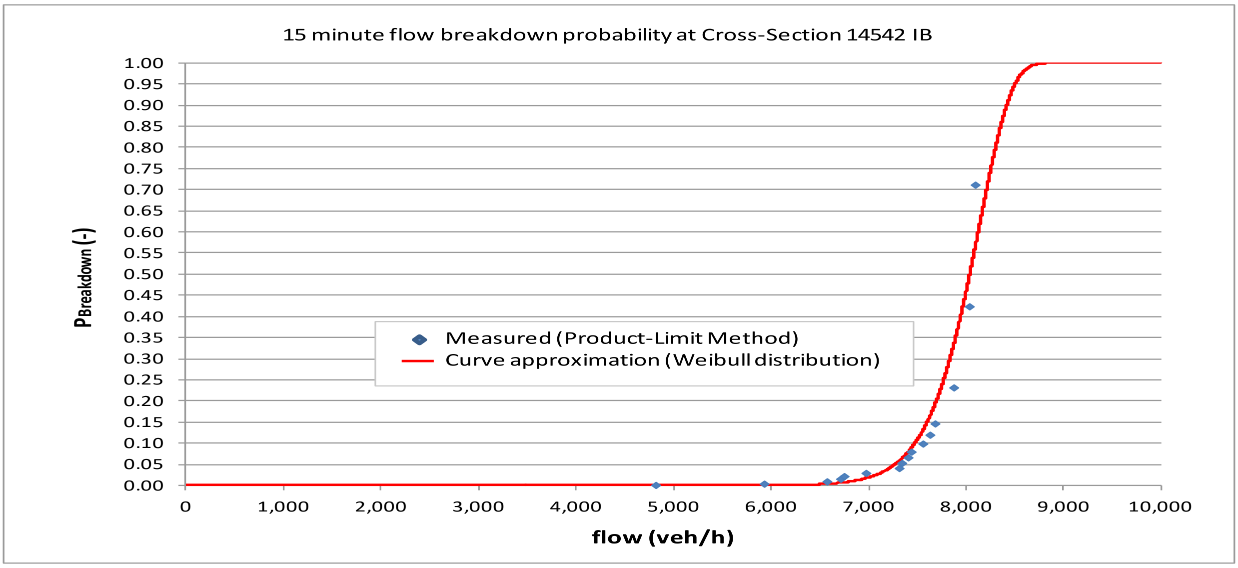

Figure 54 Probability of flow breakdown on a 4 lane motorway

Such work has been recently published by VicRoads for the purposes of road planning and design and provides much insight in to operations of the motorway where "Maximum Sustainable Flow Values" (MSFV) can be determined on the basis of probability where VicRoads has chosen a 10% probability of flow breakdown in any 3 hour period as being the reference point for providing reliable and safe operations and thus travel conditions for the community.

Similar work has been the subject of an as yet unpublished report by M Papageorgiou, TUC where it can be shown in traffic modeling that it is possible to set twofold objectives of:

1. improving the safety conditions, (i.e. minimizing the expected number of crashes), and
2. reducing the total time spent by the road users in the network (i.e. minimise delay), whilst maintaining a quality of flow and reliable traffic conditions for as many road users as possible

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[187] i.e. maximum sustainable flow values used by VicRoads

Therefore these twofold objectives can now be linked to provide safer motorways. This paper also investigates the relationship between two separate traffic control objectives, by assessing whether a substantial reduction of traffic congestion has a significant impact on the improvement of the safety level. Hence it is now possible to operate a "Managed Motorway" as a "closed system" using feedback control to optimise for both safety and efficient traffic flow, particularly when control system's target conditions consistent with achieving a 10% chance of failure in three hour period.

The relationships between traffic flow and safety has been generally overlooked or not appreciated by road safety practitioners doing research on motorway crashes. Even those with an understanding of these phenomena often do not have accurate enough traffic data to observe the problem in the traffic data (e.g. minimum 1-minute data resolution, at the lane level is required to observe and measure these problems). Simple road safety narratives often state slowing speed only results in a few minutes extra travel times for everyone, however in the case of the motorway this is often 10-20 minutes extra travel time for tens of thousands of motorists, and adds up to many thousands of hours of delay for each hour it is allowed to operate often costing the community many $millions/h. When the motorway system (as a network) is allowed to become inefficient, the crash risk is very high.

16.2 Other influences on the quality of flow

Other known influences on the quality of flow on motorways include changeable weather conditions, daytime/nighttime traffic effects and other traffic events (e.g. minor and major incidents). These other lesser-known factors that are more difficult to measure and quantify, possibly due to limited availability of data and or more likely limited investigation of the phenomena as the data is readily obtainable particularly in Australia.[188] Yet every day these matters have been observed by traffic officers in motorway operations to significantly impact the quality of traffic flow. Several critical factors which have an impact on the quality of motorway flow are discussed in more detail in the following sections.

16.2.1 Lane Shear

The frictional effects of adding additional lanes (i.e. 3, 4, 5, 6 & 7 lanes carriageways) result in further reductions in capacity per lane as each additional lane induces more friction between lanes (e.g. "Lane Shear") as the necessary lane changing activity increases disproportionally as additional lanes are added. Refer (Figure 55: Corridor Maximum Sustainable Flow Rates under various lane configurations) below. This phenomenon is omitted from the methodology used in the USA, HCM (USA Highway Capacity Manual, 2010) which are adopted widely in Australia, particularly as they are referenced widely in AustRoads guidelines. The crash risk rises faster as more lanes are added particularly beyond 3 or 4 lanes.

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[188] 20 second motorway data has been available in Australia since the mid 1980's

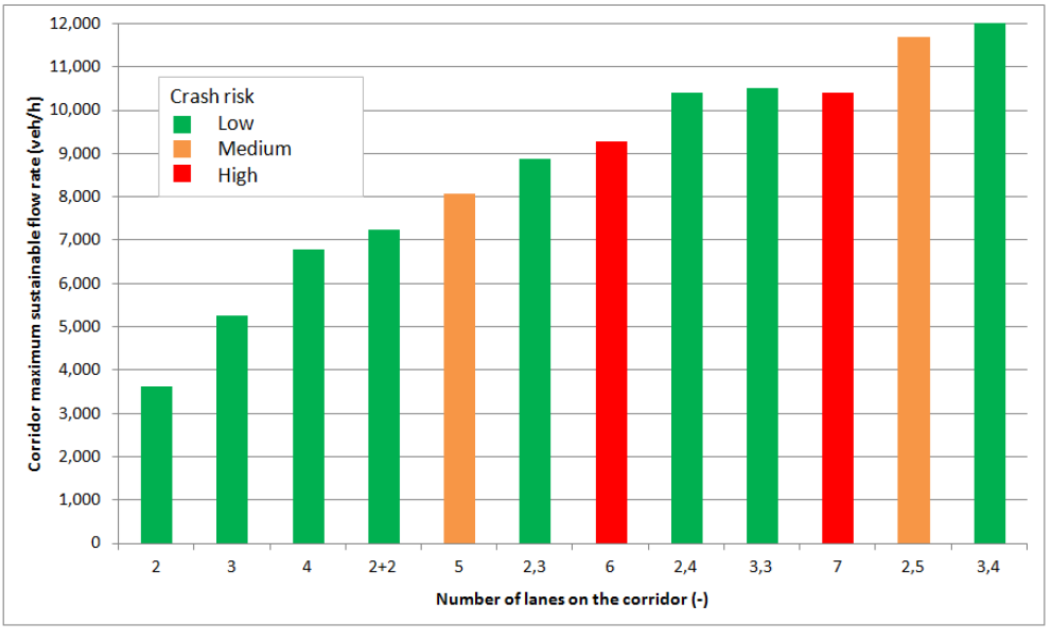

Figure 55: Corridor Maximum Sustainable Flow Rates under various lane configurations

16.2.2 Origin-Destination Patterns

The uncertainty of traffic demand estimation such as the dynamic nature of Origin-Destination (O-D) patterns (Davis, 1994) is potentially an important input in reducing uncertainty in data that can lead to improved motorway control systems. In the report titled "Dynamic Estimation of Origin-Destination Patterns in Freeway" (Davis, 1994) examined methods to improve the estimation of O-D patterns potentially for use in real time to improve the prediction of a motorway sections' demand and thus make better control decisions leading to higher efficiencies and improved safety.

Understanding that this phenomenon occurs in the traffic flow means that with appropriate control engineering this phenomenon can be controlled for in real time, as is the case in Victorian "Managed Motorway" Control System using HERO LIVE algorithms developed by Prof. M. Papageorgiou which seeks indirectly to control the chaos associated with temporal changes in traffic patterns O-D, lane changing behaviour and vehicle mix such as the percentage commercial vehicles.

Davis summarises by stating *" if one of the goals of a freeway ramp-metering system is to prevent the traffic demand on a given freeway section from exceeding that sections' capacity, and if the ability to predict a section's demand is subject to uncertainty, then in order to guarantee that a given set of metering rates does not cause capacity exceedances more than a specified percentage of the time, it is necessary to treat each section as having a target capacity that is lower than its nominal value".*

This is because if the average of the 60 x 1 minute flows on a motorway = the hourly capacity then assuming some randomness or distribution in the traffic flow of each of the one minute flows, a significant portion of the 1 minute flows in each hour are likely (i.e. 50% of the time), to have a value higher than the average values some of which are likely to be high enough to change the "Traffic State" increasing the motorway crash risk. Refer (Figure 56 Variations in the 1 minute flows on an urban motorway) showing fluctuations in the 1 min traffic volumes, shown in blue, on a 3 lane section of the Monash Freeway.[189] Hence the challenge in motorway optimisation and control is to smooth and constrain flows to match but not exceed the "maximum sustainable flow value" in real time, refer VicRoads Motorway Design Guide.

The randomness and the clustering of the peak 1 minute flow that actually causes the disturbance in the traffic flow known as perturbations and/or "Nucleation Events", which are the key triggers of traffic flow collapse (i.e. flow breakdown events) which cause many casualty crashes. It is noted that this phenomenon is omitted from methodology used in USA HCM (USA Highway Capacity Manual, 2010) and is not apparent in data sets smoothed at the 5, 15 and 60 minute intervals and hence "Nucleation Events" seem to have been overlooked by traffic engineers, road designers, traffic modelers and, road safety practitioners.

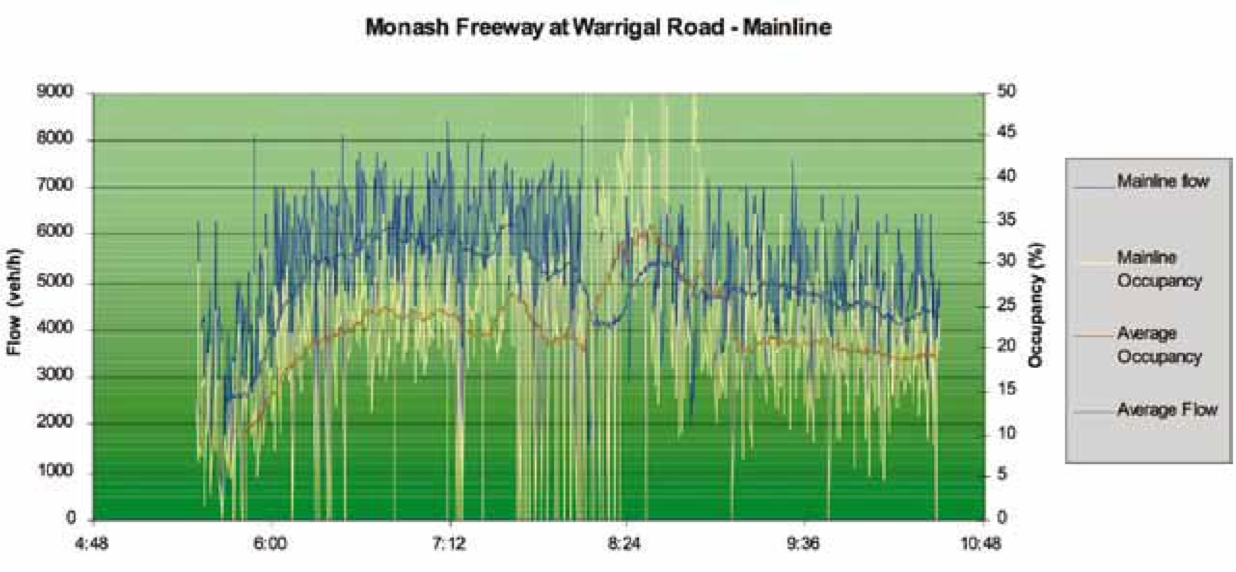

Figure 56 Variations in the 1 minute flows on an urban motorway

16.2.3 Average trip length influences lane changing intensity

Understanding that in urban Australian capital cities that the average motorway trip length is widely variable varying minute by minute across the day (i.e. temporal), yet trips are relatively short in length on average with the 50 percentile of trips typical range 3-6 interchanges or 10-15km depending on the motorway segment being evaluated. It could be implied that most trips (i.e. approximately 95% of trips) are completed in about twice the average trip length of 20-25km.

The shorter the average trip length the higher the turnover of trips per kilometre of road space and hence greater frictional effects (i.e. "Lane Shear"), as a result of lane changing. High levels of lane changing are necessary for a motorway to reach it maximum vehicle carrying capacity as all lanes need to be filled for maximum sustainable flow values to be achieved. High numbers of lane changes should not be seen as problematic when it comes to understanding urban motorway operation as it is generally a "necessary evil". However lane changing when the motorway flow is moderate to high increases the risk of flow collapse and also increases the likelihood of crashes as this is one of the common precursors (i.e. "Events as Exposure" for crash events) where large disturbances in the flow changes the "Traffic State" from "meta-stable" to "synchronised" refer

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[189] Note there was a cluster of heavy flows before motorway flow breaks down at around 8:00am.

(Table 2 The various moods of the motorway adapted from B. Kerner's Three Phase traffic theory).

It is evident that this additional friction has a significant effect of lowering the per lane capacity of the carriageway (refer discussion in Section 16.2 Other influences on the quality of flow) above. In Victoria, it has recently been possible to measure some of the lane changing activity with "vehicle event data" that records unique vehicle attributes such as length, width, wheel diameters, and axles numbers. Future "Sustainable Traffic Flow values maybe require a modifying factor relating to shorter or longer trip length and this will have a direct correlation for road safety as lane changing events elevate crash risk and can potentially be correlated in real time to average trip length. This is partially taken into account in current traffic control system strategies by using surrogates to measure the chaos associated with increasing "Lane Shear" in real time through the use of real-time optimising algorithms.

In a study of traffic oscillations (i.e. stop-go waves), and vehicle lane change maneuvers (Ahn S, Cassidy M J) analysis reveals the influence of lane changing maneuvers on oscillations in traffic as motorists squeezed their way into neighbouring lanes to utilize every last metre of available road space. These oscillations once formed sometimes grow in amplitude and propagate upstream for many kilometres. **In (Ahn S, Cassidy M J) study, lane changing triggered every bottleneck formation and growth in oscillations and these findings are notable considering most scientific literature generally ignores the role of lane changing and instead concentrates on "car following" as being the primary cause of traffic behaviour.** Hence lane changing is a compounding factor in understanding the motorway road safety problem. This was confirmed on the Churchill Fellowship by traffic theory physicists M. Treiber and B Kerner.

Therefore techniques in motorway design and operations that lead to reduced lane changing activity may, in fact, improve motorway operational outcomes (e.g. use of barrier lines to restrict lane changing thorough critical bottleneck sections) as used in Germany and elsewhere in Europe, and by a semi-solid line marking, as used on the M1 Freeway Toorak Rd to High Street, and on the West Gate Bridge in Melbourne.

Although this phenomenon is omitted from many current traffic design guides, there are design solutions that can reduce the turbulence within the carriageway with traffic moving between lanes (i.e. which reduce "Lane Shear") such as building more separated carriageways rather than simply widening. It is likely on motorways that a maximum of 3 or 4 lane carriageways might be the physical limit for safety and traffic flow optimization based on the additional complexity induced with each additional lane, and which seems to be corresponding to a limitation of human capacity not to make errors when faced with increasing complexity.[190] Widening motorways beyond 3 or 4 lane carriageways requires considerable analysis and care as from a road safety and traffic efficiency perspective it may be best to divide the carriageway into two carriageways (i.e. through use of a collector-distributor carriageway).

16.3 Further understanding of the fundamental traffic flow relationships

From observation and measurement of motorway traffic operations, it is becoming clear that the fundamental (i.e. speed, flow and density), relationships vary significantly:

- for each individual freeway lane i.e. 1, 2, 3, 4, 5, 6 and 7 lanes within a carriageway, particularly as each additional lane disproportionately increases the number of necessary

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[190] Refer VicRoads Motorway Design Guide

lane changes required across the lane line boundary;

- for carriageways comprising different lane numbers, for the reason quoted above;
- dependant on various geometric constraints (e.g. grades, curvature, lane width and shoulder width);
- dependant on the instantaneous network loading (i.e. vehicle mix and O-D patterns) which influences the rate of lane changing required;
- dependant on the actions of the real-time dynamic ITS control systems acting on the operational outcomes with ITS tools such as:
  - i) Coordinated Ramp Metering (CRM),
  - ii) Variable Speed Limits (VSL),
  - iii) Dynamic VSL (DVSL),
  - iv) Lane Control Systems (LCS),
  - v) Traveller Information (TI).[191]

Further discussion as to why the fundamental relationships need to be understood at the lane level and at the carriageway level as the fundamental relationship varies with each additional lane added to the motorway and at each motorway section as discussed in Section 16.2. Typically as each additional lane is added there is a capacity reduction[192] in terms of the capacity per lane. As discussed below research by (Kononov, Bailey, Allery, 2008) indicating that adding more lanes can exponentially increase the risk of motorway crashes particularly when traffic volumes exceed 90,000 vehicles per day on a 3[193] lane motorway, a situation that now occurs regularly on motorways in most Australian capital cities.

Exceptions to this additional lanes phenomena, as seen in research literature, are between 1 and 2 lane carriageways where a long length of one lane carriageway has the potential for problematic operational issues, as capacity is determined by the slowest moving vehicle in the single lane as overtaking is not possible. However, the road safety implications of increasing from one lane to 2 lanes (i.e. the well publicised 2+1 lane treatment used commonly on Sweden's Highways) is that the terminus treatment where 2 lanes are reduced to one lane, can significantly increase the crash rates (i.e. discussed in Section 1.4) above. Also the capacity of these 2+1 lane facilities is typically low only 1200-1300 veh/h per carriageway which is restricted by the termination treatment and hence they only assist overtaking, rather than provide any increase in flow and hence care is needed when these treatments are deployed on motorways or divided highways operation when traffic density rises above LOS A and B or approximately 1100 – 1200 veh/h even for some short period of time (i.e. seconds or minutes).

Other exceptions occur as a result of various operational regimes such in Germany with truck bans in certain lanes where on 4 lane autobahns there are 2 clear "car only" lanes that can result in much higher lane capacities than evidence on a 3 lane autobahn. The higher capacity is derived from the much higher average speeds on a 4 lane autobahn (i.e. >120-140km/h), with 2 clear lanes dedicated to cars only[194]. However at these high volumes which occurs at higher speeds, the risk of flow collapse may be much higher and hence if a risk-based approach is used to determine capacity (i.e. 10% probability of flow breakdown in any 3 hr period), the values might be lower.

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[191] Can influence driver choices and hence operational outcomes i.e. variable messages and other real time roadside or in-vehicle traffic information including public news bulletins etc.

[192] Typically 4% capacity reduction measured across all lanes

[193] 2 lane motorways tend to have considerably less complexity referFigure 73 Number of conflict points in relation to Lane numbers

[194] Very few examples of 4 lane autobahns currently exist to provide a statistically sound analysis or basis for broader application

In Australia it is important not to read in too much from other country's reported capacity values as these values are often measured on more semi-rural type motorways (e.g. autobahns) and when compared to motorways in large congested Australian capital cities, these rural motorways generally have much larger distances between interchanges (e.g. 7-10 km interchange spacing) and much longer average trip lengths which reduces lane changing friction (i.e. "Lane Shear") discussed above.

Sometimes these other motorways have lower capacities than which are measured on a 4 lane "Managed Motorway" facilities in Australia. Hence it does not follow that adopting such an operational regime (e.g. "car only" lanes) would translate to Australia and provide improved operational or safety benefits within the congested urban corridor context. This is because as origin-destination patterns influence average trips length, and the default speed limits are quite different in Australian capital cities, where motorways now take on much of the arterial road function as well. Road planners and designers have also contributed to this by allowing much closer spaced interchanges in an attempt to service more trips, all of which combine to cause quite different operating characteristics refer the Section1.1.4 and 1.4 above.

16.4 Relationships between motorway efficiency and safety

The evidence is emerging that a well "Managed Motorway" is also a safe motorway.[195] The level of additional safety provided by a "Managed Motorway" can no longer be ignored and there is potential for further improvements to road safety outcomes of congested urban motorways now that there is further understanding of the mechanisms involved in crash causation.

The relationship between efficient motorway operations and road safety has been ignored for too long and, hence this section is included to provide much-needed information so that the safety of future motorways are not compromised by decision makers, road designers or traffic operators. The following Figure 57 Comparison of crash rates on Melbourne's motorways btw 2011 and 2015 reveals the measured benefits of "Managed Motorway" programs. The first two motorways (Monash Freeway and Princes Freeway West) are only deemed to be managed by the relevant VicRoads "Managed Motorway" criteria[196] and these two motorways have a much lower crash rate being in the order of 25-30% lower.

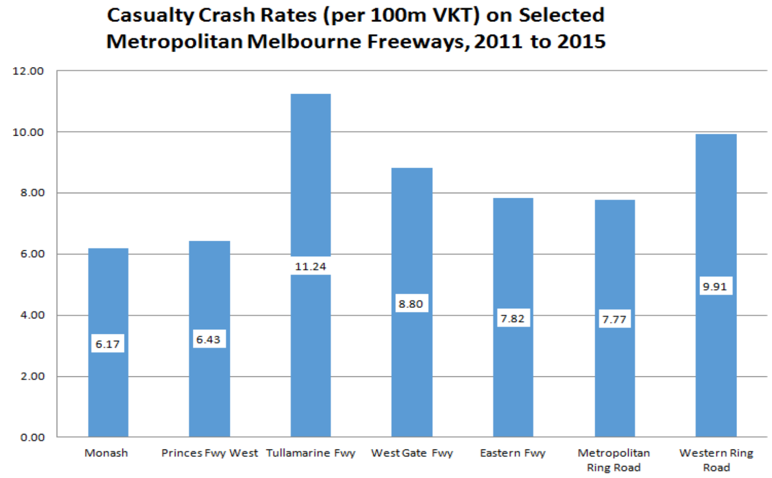

Figure 57 Comparison of crash rates on Melbourne's motorways btw 2011 and 2015

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[195] refer as yet currently unpublished work Prof. Markos Papageorgiou.

[196] refer (Gaffney J, Lam P, Somers A, Boddington K, Johnston D, 2017)

From the beginning of the "Managed Motorway" program in Victoria which commenced in 2007, it was understood that one of the key mechanisms at play in the majority of motorway FSI crashes was the random occurrence of very high traffic densities (veh/km/ln/min) which are measured by the surrogate "lane occupancy" from sensors in the road pavement. High traffic density was what "Managed Motorway" operational control system sought to reduce. This mechanism can now be shown in traffic theory discussed with Boris Kerner and Martin Treiber as part of the Churchill Fellowship.

16.4.1 Safety through Management of Motorways

The urban motorway safety problem arises when certain "Traffic States", as identified by (Golob T, Recker W. Alvarez V, 2003) are activated within the traffic flow as traffic volumes and density rise. Reducing the occurrence of high density has been demonstrated by (Gaffney J, Lam P, Somers A, Boddington K, Johnston D, 2017), to a large degree when congestion has been reduced and traffic flows smoother, which has resulted in a 31% crash reduction over the 5 year periods measured over a motorway length of 25.5km including 14 interchanges.

Crash rates can be significantly reduced (i.e. 31%) by eliminating the causes of the speed variations within the traffic stream through the management of real-time traffic densities, below the point that will trigger stop-start conditions and shockwave formation, leading to both oscillating speeds and stationary queues within the traffic stream. This is the outcome of "Managed Motorway" initiatives and one of the keys to reducing crashes rates even though the safety outcome was achieved at significantly higher average speeds (+20km/h). The higher speed outcome tends to contradict the road safety narrative of the relationship between speed and crashes, which now needs to be extended describing safety in terms of its relationship to traffic density and other compounding factors that increase complexity for drivers such as increasing lane numbers resulting in a disproportionate increase in lane changing. The following (Figure 58 Relative crash rates on Melbourne urban motorway network) shows the effect of Melbourne's first "Managed Motorway" completed during 2009 being the Monash Freeway.

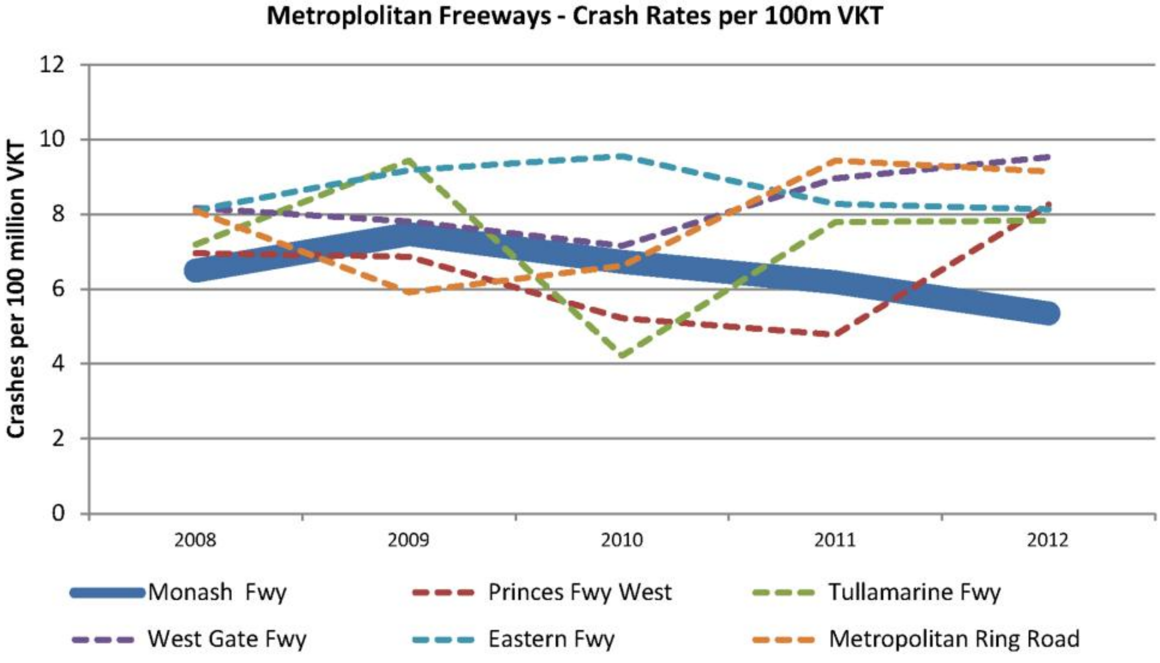
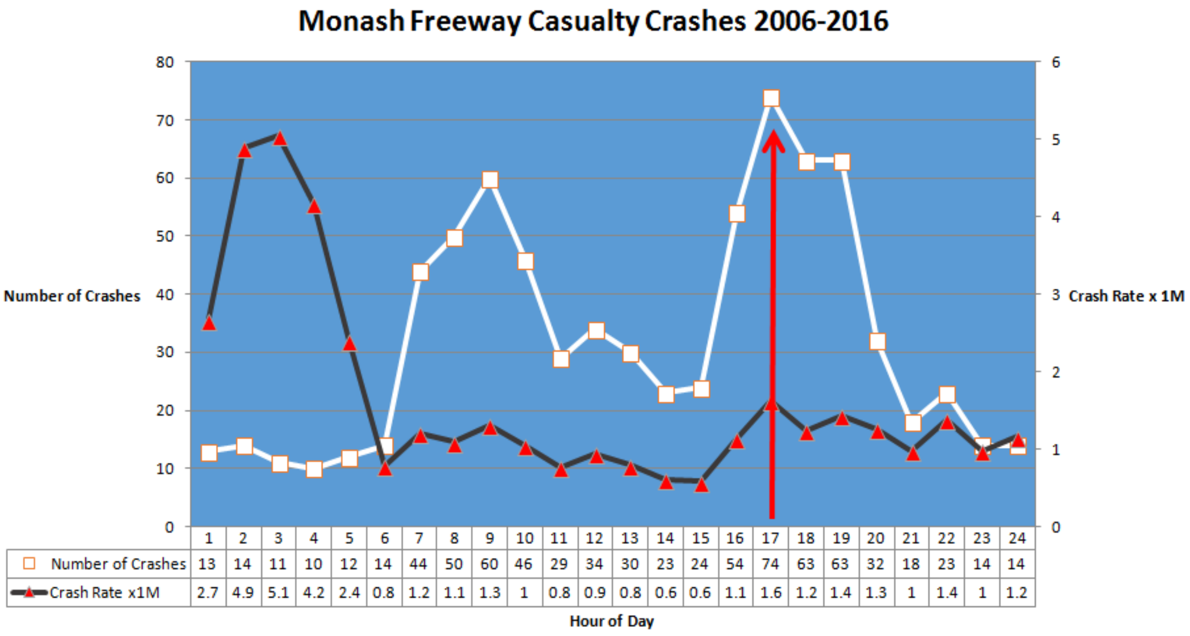


Figure 58 Relative crash rates on Melbourne urban motorway network

16.5 Crash statistics can mask the nature of the crash problem(s)

One of the major reasons the motorway safety problem has been often ignored is due to the use of inappropriate crash statistics which masks the problem. Whilst the crash rates are highest in the nighttime hours (e.g. 2 am), identified by the small blip shown in (Figure 59 Profile of crashes on the Monash Freeway - Warrigal Rd to Clyde Rd - by hour of day) when traffic volumes are very low. However, the number of casualty crashes are many times higher when the traffic volumes are highest (refer red arrow in (Figure 59 Profile of crashes on the Monash Freeway - Warrigal Rd to Clyde Rd - by hour of day). In road safety terms the best return on investment will be developing countermeasures to address the very large number of crashes with a low crash rate (i.e. crash rate of 1.6 at 17:00 or 5pm) as shown in the figure masked by the very high exposure rate, discussed in (Section 6.3 The scale and nature of motorway demands).



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
☐ Number of Crashes	13	14	11	10	12	14	44	50	60	46	29	34	30	23	24	54	74	63	63	32	18	23	14	14
▲ Crash Rate x1M	2.7	4.9	5.1	4.2	2.4	0.8	1.2	1.1	1.3	1	0.8	0.9	0.8	0.6	0.6	1.1	1.6	1.2	1.4	1.3	1	1.4	1	1.2

Figure 59 Casualty crashes profile on the Monash Freeway - Warrigal to Clyde Rd - by hour of day

16.6 Casualty crashes numbers tend to mirror traffic demands

Whilst motorways, in general, have a very good safety record from an overall crash rate perspective, it is apparent that the number of casualty crashes tends to mirror the traffic demands or the “Traffic State” as measured by “lane occupancy”. This section explores some of the international findings on the strong link between congestion (e.g. stop-start conditions) and, crash rate as well as provides discussion that links the lane changing rate that is maximised when the motorway is operating at or near capacity, the number of conflict points within the motorway stream and, the corresponding complexity of the driving task. Under such circumstances, the crash rate has been shown internationally to be 5-6 time higher which is reflected in (Figure 59 Profile of crashes on the Monash Freeway - Warrigal Rd to Clyde Rd - by hour of day) above.

Shown in (Figure 60 Breakdown of casualty crashes by crash type by hour of day) is the number of casualty crashes on the Monash Freeway. When this data is combined with (Figure 61 Typical traffic volume profile Melbourne) it reveals that overall causality rates to a large extent mirrors the travel exposure (i.e. it tends to mirror the daily traffic volume profile) with higher number of injuries during the morning and afternoon peak periods, when the moderate to heavy and congested "Traffic States" are more likely to occur. This phenomenon was also clearly demonstrated on many European motorways. Therefore is it a coincidence that as motorways have been widened over the past 10-15 years in Australia and Europe to carry more of the arterial road traffic, that crash numbers are rising, despite the continuing focus and increasing effort on road safety measures and programs?

The following (Figure 60 Breakdown of casualty crashes by crash type by hour of day – Monash Freeway), shows the 3 typical types: "Rear Ends", "Lane Change" and "Run-of-the-Road" crashes and how their mix and magnitude changes over the 24 hours of the day. This changing mix is readily explainable by the changing traffic conditions and the rapidly varying "Traffic State" or moods described in Section 5, (An Explanation of the Complexities Involved in Motorway Operation). During peak periods the "Rear End" and "Side Swipe" crashes dominate which relate to higher traffic volumes.

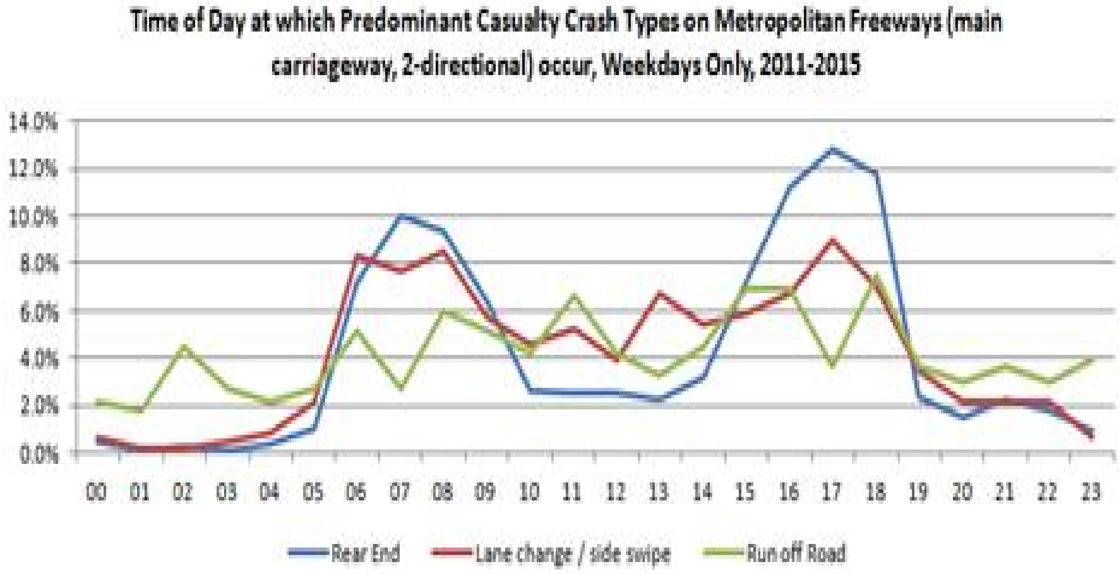


Figure 60 Breakdown of casualty crashes by crash type by hour of day – Monash Freeway

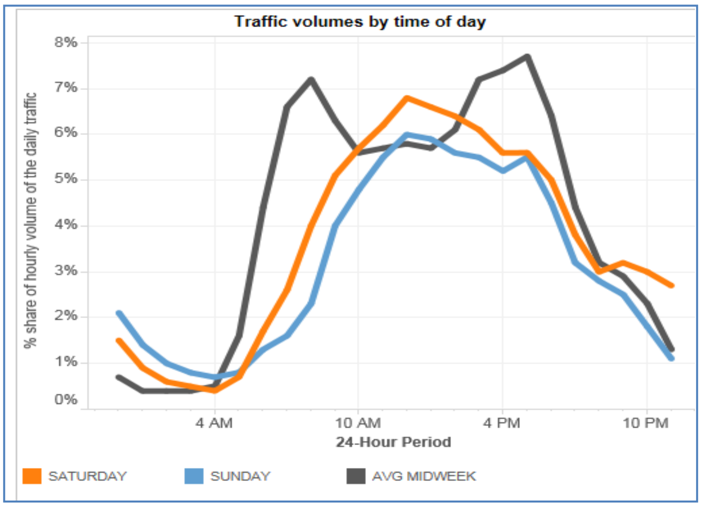


Figure 61 Typical traffic volume profile Melbourne motorways

16.7 The influence of motorway travel on casualty crashes

The following document from the Netherlands, Institute for Road Safety Research (SWOV, 2007) has indicated that although 40% of vehicle kilometres are travelled (VkT) on their motorways, a similar rate as in Australian capital cities, yet no more than 10% of all fatality crashes occur on them.[197] By observation the Netherlands has quite different travel patterns to the Australian capital cities as most of their motorway travel although reasonably congested at some locations and at some times of the day could be considered to be more interurban travel (i.e. Utrecht to Den Haag or Amsterdam to Rotterdam) and would be more comparable to Australia motorways (e.g. Melbourne to Geelong or Sydney to Wollongong or Newcastle) and, hence comparisons or similarities will always depend on what contexts are compared.

By comparison in Melbourne urban motorway crashes comprise about 15% of all urban crashes and similar extent fatalities (refer Figure 63 Urban fatal crashes in Melbourne by arterial road and freeway), however the daily traffic volumes are much higher over the 24hr period than on motorways in the Netherlands, which by comparison still tend to have relatively short (i.e. only about 2 hrs) well-defined peaks comprising largely commuter travel.

The Dutch report also states "***The reason for the annual increase in motor vehicle kilometres* (of travel) *not resulting in a proportional increase in fatal crashes lies largely in the fact that most of the increase goes to the relatively safe motorways***". This fact has most likely been replicated across Australia, as the urban motorway network has done much of the heavy lifting in terms of doubling the urban VKT from 20% to 40% in the past 20 years, whilst still maintaining only 7% of the urban road network's length when measured in lane kilometres.

By comparison to the motorway network, the total travel on the arterial road network is relatively stable (refer Figure 62 Total travel on Melbourne's urban freeway and arterial road network) between 2005 and 2014. Also as discussed in Section 7 Crash Risk a Function of "Events of Exposure", such a strong disproportional increase in crashes would not be expected based AADT or number of encounters as shown in (Figure 11 Shape of relationship between relative exposure and accident rate) unless some new mechanism was involved or in the case of motorways are activated (i.e. density >LOS C).

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[197] Note. This figure was published 10 years ago i.e. is now dated because of the. "time trend bias", 10 years later the VkT is now 50% and the crash rate would have expected to also have risen

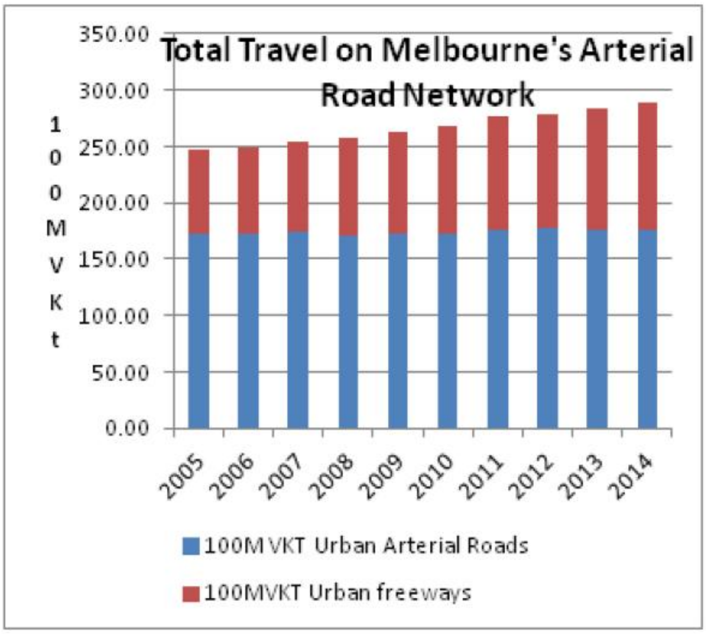


Figure 62 Total travel on Melbourne's urban freeway and arterial road network

In Melbourne, the total **fatality crashes** on freeways represent about 15% of all urban fatalities on arterial roads when averaged over the last 4 years (refer Figure 63 Urban fatal crashes in Melbourne by arterial road and freeway). The total **casualty crashes** represent a similar amount being 14% (refer Figure 64 Total casualty crashes on Melbourne's arterial road network), averaged over the same period.

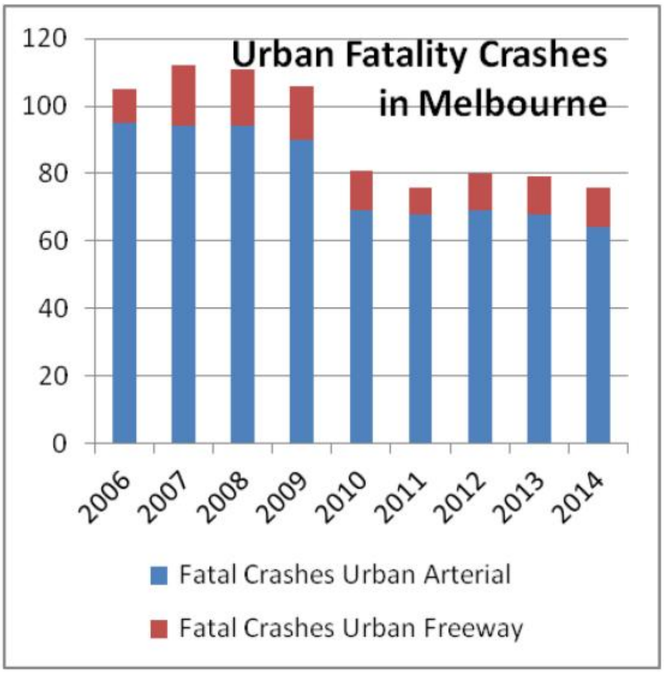


Figure 63 Urban fatal crashes in Melbourne by arterial road and freeway

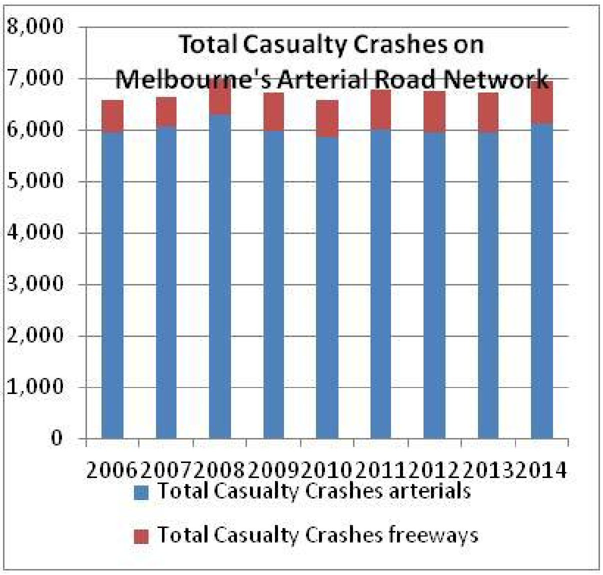


Figure 64 Total casualty crashes on Melbourne's arterial road network

The urban motorway **fatality crash** rate per 100M VkT is 3.8 times safer (measured over the past 4 years) than the arterial road crash rate as the arterial road crash rate is 0.38 per 100mVkT compared to 0.11 per 100m VkT for freeways (refer Figure 65 Freeway vs. arterial road crash rate per 100m VkT).

A comparison of the Freeway vs Arterial road causality crash rate per 100m VkT is shown in (Figure 66 Freeway vs. arterial road casualty crash rate comparison per 100MVkT). The arterial road is 25 times higher **casualty rate** per 100m VKT averaged over the last 4 years. **This makes the freeway approximately 25 times safer to drive from a casualty crash perspective and 4 times safer from a fatality crash perspective and hence the transference of travel, over recent decades (i.e. 100% growth in 15-20years) towards the freeway will have had a significant effect slowing or reducing the growth in fatalities,** a factor that has not been acknowledged or attributed by the road safety community in Australia. Thus the road system is changing in ways that explain crash reductions and changes over time, however, we must be looking specifically for this phenomena to find it. As quoted from Thomas Kuhn **"You don't see something until you have the right metaphor to let you perceive it".**

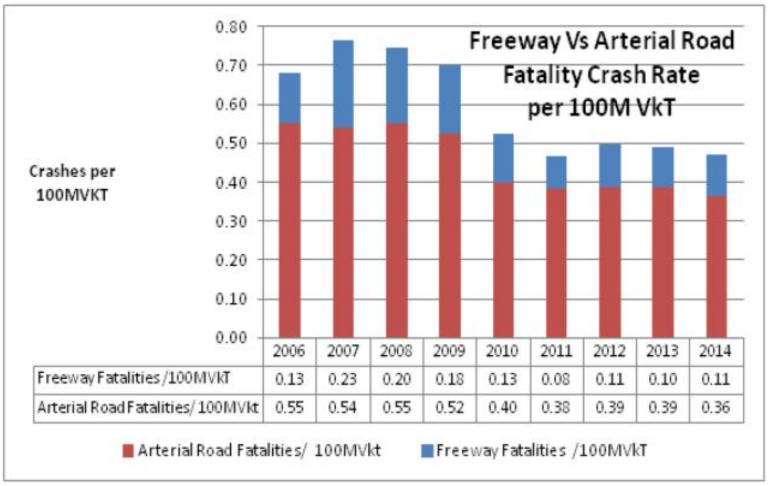
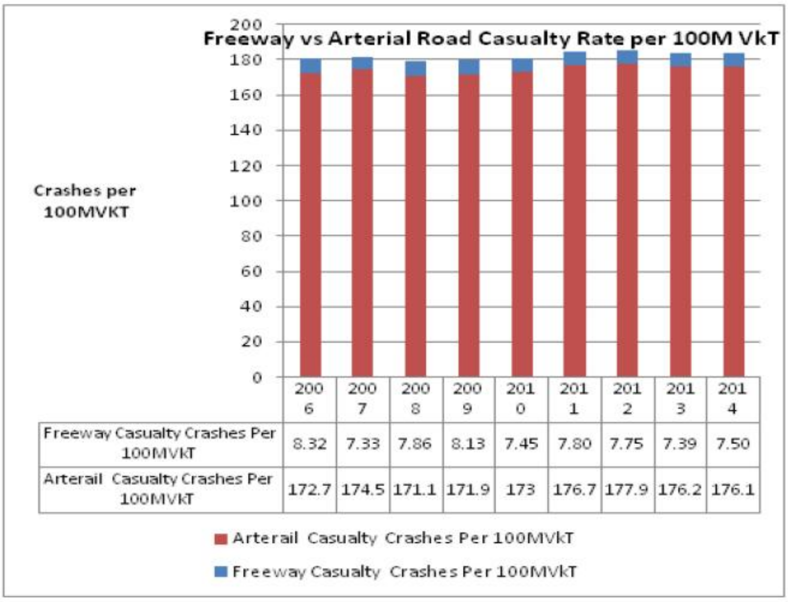


Figure 65 Freeway vs. arterial road crash rate per 100m VkT



	2006	2007	2008	2009	2010	2011	2012	2013	2014
Freeway Casualty Crashes Per 100MVkT	8.32	7.33	7.86	8.13	7.45	7.80	7.75	7.39	7.50
Arterail Casualty Crashes Per 100MVkT	172.7	174.5	171.1	171.9	173	176.7	177.9	176.2	176.1

Figure 66 Freeway vs. arterial road casualty crash rate comparison per 100MVkT

It is surmised that if the last 10-15 years the extra growth in urban travel had of been shared more equitably between the motorway and arterial road networks (i.e. shared 50/50), over the past decade or so Victoria would have had I the order of 10 or more fatalities per year and more than 600 extra causality crashes per year. It could be concluded therefore that the disproportionate transference of travel towards the motorway network has reduced the urban annual toll each year in the order of 10% which supports the findings in the Netherlands discussed above. Hence another example of missing attribution in road safety analysis discussed in (Appendix C Nine Areas of Concern for Road Safety Science).

These findings in the Netherlands do not necessarily concur within much of the published Australian research and promotional material on mechanisms that reduce the road toll, however as stated above it is acknowledged by (The Netherlands - Institute for Road Safety Research, 2007) that their ***"main concern is once the motorway network is full and congestion continues to increase, is whether they as an organisation should be actively encouraging travel back towards the less safe arterial roads?"*** Is it possible that this is already occurring in Europe and in our Australian capital cities?

Unfortunately 10 years later, in 2017 this is highly likely to have already happening since 2007 and hence this in part explains why a number of leading countries in road safety including the Netherlands and Sweden are seeing a gradual rise in the road toll particularly on divided highways and motorways and on other roads including arterial roads networks as traffic growth spreads demand back to less safe roads. Hence it is likely in the near future, as urban motorway networks approach their defined capacity limits, that urban crash rates will again begin to rise.

16.7.1 Peak spreading currently masking the extent of the problem

Urban motorways in Australian cities currently only are able to maintain high levels of traffic growth by the mechanism of "peak spreading" and the extent that this is achievable will reduce each year due to limits of human activity (i.e. will enough people want to travel or work at 3 or 4 am?) and, the fact that the volumes in the middle of the day between the morning and afternoon peaks have little room for additional traffic growth. Hence in the very near future the morning peak and the afternoon peak will meet up as the high off-peak motorway travel is already around 80% of peak period travel in some parts of the urban motorway network. Motorways typically have higher commercial vehicle numbers during the middle of the day, thus when traffic volumes are measured in Passenger Car Units (PCU) a lower capacity results (i.e. 10% lower) which means many urban motorway sections are currently operating close to capacity throughout much of the day.

As revealed in (Figure 67 Distribution of Melbourne traffic growth 2009/2010 to 2013/2014 which demonstrates how the urban arterial road network growth appears to have stagnated or declineded compared to the freeway network over the past 4 years. It is likely that the congestion on the arterial road network is lowering its carrying capacity, as well as transport policies that are reallocating road space and signal phase time to other modes, is also spreading peaks periods and transferring additional traffic to the local road networks where travel is not currently being measured or reported systematically for use in road safety statistics.

16.8 Research on freeway crashes in relations to “the Traffic States”

High crash occurrence during slower or stationary traffic conditions (e.g. heavily congested – the car park conditions) have been found to be closely related on motorways, however, under these traffic conditions, crashes are more likely to involve “property damage” only. In free flow traffic conditions where average speeds are above 85km/h vehicles tend to have reduced degrees of conflict and hence crash numbers are also lower. This coincides with recent findings which identified two major crash clusters in the pre-congested and light congestion “Traffic State” (i.e. between the light and the congested traffic conditions) at speeds in the moderate range of 70-85km/h.

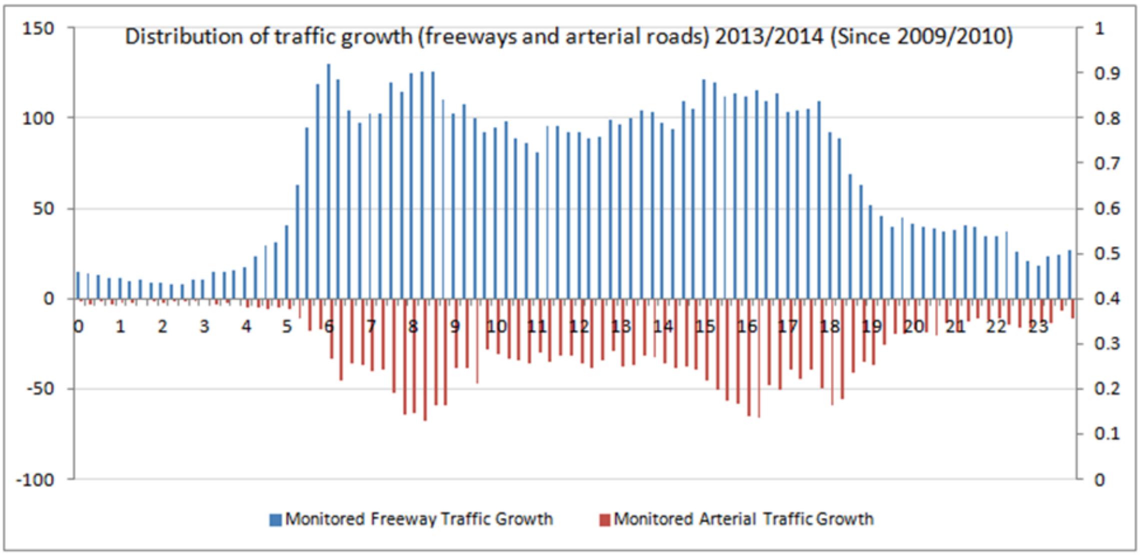


Figure 67 Distribution of Melbourne traffic growth 2009/2010 to 2013/2014

Motorway traffic crashes under variable traffic conditions, such as growth or dissipation of congestion, oscillatory waves or stop-start conditions, have not been investigated systematically particularly by Australian Road Safety Research Institutions. Since traffic patterns and their corresponding driver behaviours’ vary substantially with “Traffic States”, crash occurrence and its characteristics may also vary concurrently. This has been confirmed by recent crash analysis where the distribution of crash types can be observed to be related to traffic density (i.e. lane occupancy) and is readily explainable by traffic science. Therefore, (Yeo H, Jang K, Skabardonis A, Kang S, 2014) found that it was necessary to categorise “Traffic States” regarding distinct traffic conditions for evaluating the relation between traffic states and crash occurrences.

The study by (Yeo H, Jang K, Skabardonis A, Kang S, 2014) identified 4 "Traffic States" as first articulated by (Lighthill and Whitham, 1955) against which to analyse crashes. These "Traffic States" are as follows:

1. *"FF state – Both upstream and downstream traffic states indicate free flow, and the freeway section in-between is also in the free flow state;*
2. *BN state – The section includes an active bottleneck. In other words, traffic is congested at upstream and free-flowing at downstream;*
3. *BQ state – A road section contains a back-of-queue. Traffic at upstream location is free flow while downstream location is congested. The location of BQ may move as the traffic wave propagates either forward or backward;*
4. *CT state – Both the upstream and downstream ends of a freeway section are congested. Because of the existence of stop-and-go."*

Exploring this further, crash occurrences may be related to conditions such as:

- the impact of road geometry, which seems to be more pronounced during near capacity traffic volumes when the motorway functionality (road design/geometrics) is put under high levels of stress. This problem is another example of context change for undertaking crash analysis as motorways often have not been designed without understanding the complexities introduced when traffic demand exceeds design capacity for considerable periods of the day;

- at locations with stronger merging, diverging activity or more severe vertical and/or horizontal alignments which impact on traffic flow (i.e. the cause of traffic disturbances know as perturbations) and, which increase the complexity of the driving task. Small geometric changes in grade (i.e. 3%) or curve radii (i.e. radius <750m) can impact weaving and increase the likelihood of perturbations in the traffic flow (i.e. "Nucleation events") which are likely to be the trigger mechanisms for crashes in medium and heavy traffic flows;

- vehicles travelling too close to each other at slower speed and, thus, are likely to have increased degree of conflicts in congested traffic conditions, - this includes both headway (forward space) and lateral clearance (position in lane sideways);

- higher differential speeds where faster traffic approaches slower moving traffic or queues and do not make appropriate speed reductions. A few motorists may even perceive that the speed limit is their right even though the majority of motorists have already adjusted by slowing down. As discussed elsewhere in this paper these faster drivers may actually trigger the perturbations that cause the crash (i.e. 8-10 vehicles behind them). It is also noted elsewhere in this paper that research suggests higher differential speed[198] is not a significant issue relating to crash causation but rather higher "mean speed". However, these studies may not have studied the urban motorways crash context in detail;

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[198] A topic that requires thorough research at the micro level of data matched to actual crash events rather than assumed average speed or speeds plus or minus 5mins or more

- increased lane change activity that naturally occurs as a motorways load up, as volumes approach capacity. Other international research (Pompigna A, Rupi F, 2015) (Pompigna, 2015) reveals that it is usually the fast lane that is the last lane to reach capacity and, filling the fast lane requires more vehicles to move across all the other lanes to fill it up and then unload it. This phenomenon may vary depending on motorway context (i.e. trip length, origin-destination patterns, various countries road rules such as trucks stay right rule in Europe and “car only” lanes), and various other driver behaviours including cultural issues;

- Significant differential speeds associated the “get ahead” phenomena in congested traffic conditions when a few motorists think there is advantage to be made by making additional, and often risky lane change maneuvers (swooping) to “get ahead” even though the majority of motorists have adjusted by slowing down and gaps (i.e. measured in both distance and time) in the traffic flow have reduced. This phenomenon also occurs when traffic patterns change (e.g. at the sub 1 min level) and a particular lane appears to have less traffic so motorists endeavour to take advantage of these apparent opportunities.

- A follow-up report by (Song S, Yeo H, 2012) provides further insight into estimating collision rates based on the “Traffic State”. This work is important as each crash has been linked to the actual condition on the freeway at the time and location of the crash. This collision rates (measured in Collisions/(Vehicle Miles or Travel (VMT)& Vehicle Hours of Travel (VHT) x1,000,000 for Rear End (RE)), Side Swipe (SS) and Others crashes are shown below in Figure 68. The speeds are shown in (c) and (d) are related to the average upstream and downstream speeds whilst (a) and (b) are the difference in upstream and downstream speed. It is clear from this work that crash rates decrease as average speed increase particularly above 35mph (or about 60km/h). This work is supported as being very important, however, a closer look at crashes at the micro resolution of data (i.e. at the 1minute level) at both the carriageway and the lane level reveals much more detail about crash causations rather than a more general indicator. Unfortunately, the report does not link crash severity to these metrics.

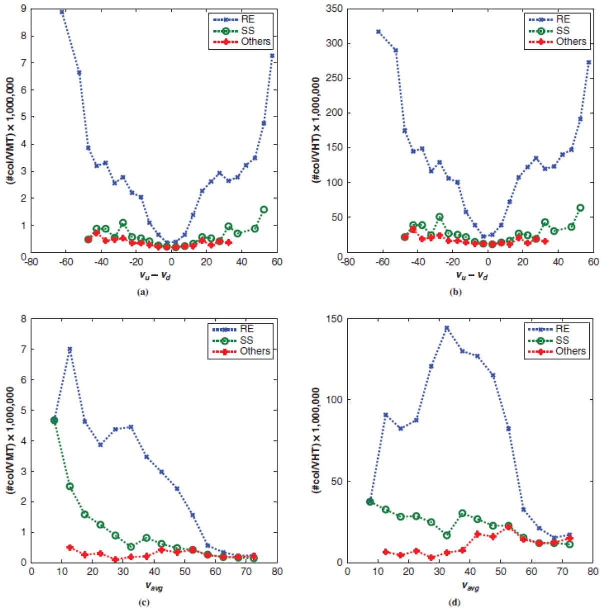

FIGURE 4 Collision rate and speed variables for each traffic state: (*a*) collision rate and speed difference for VMT, (*b*) collision rate and speed difference for VHT, (*c*) collision rate and average speed for VMT, and (*d*) collision rate and average speed for VHT (RE = rear-end; SS = sideswipe).

Figure 68 Collision rates and speed variables for each “Traffic State”

Research from many road safety studies often seems to present mixed findings that higher speeds can both increase and decrease crash rates. Some crash analyses seem to have tended to avoid the congested period on the belief/assumption that these casualty crashes are less serious from an injury perspective which is not the case on urban freeways[199] refer (Figure 69 Casualty crashes on metropolitan freeways by severity showing the profile of all casualty and fatality on the Monash Freeway. Hence most analysis is done at the macro level, (i.e. daily profiles or Annual Average Daily Travel (AADT)) or even based on posted speed limits both of which miss the detail of the changing nature of the "Traffic States" over the day. Such analysis of any road motorway or arterial road is no longer considered detailed enough to identify crash causation mechanisms, particularly with urban roads where their "Traffic State" can change significantly at the hourly level of data aggregation across the day and which is revealed even more starkly when measured at the 1 min traffic flows where the actual triggers of crash events can be seen.

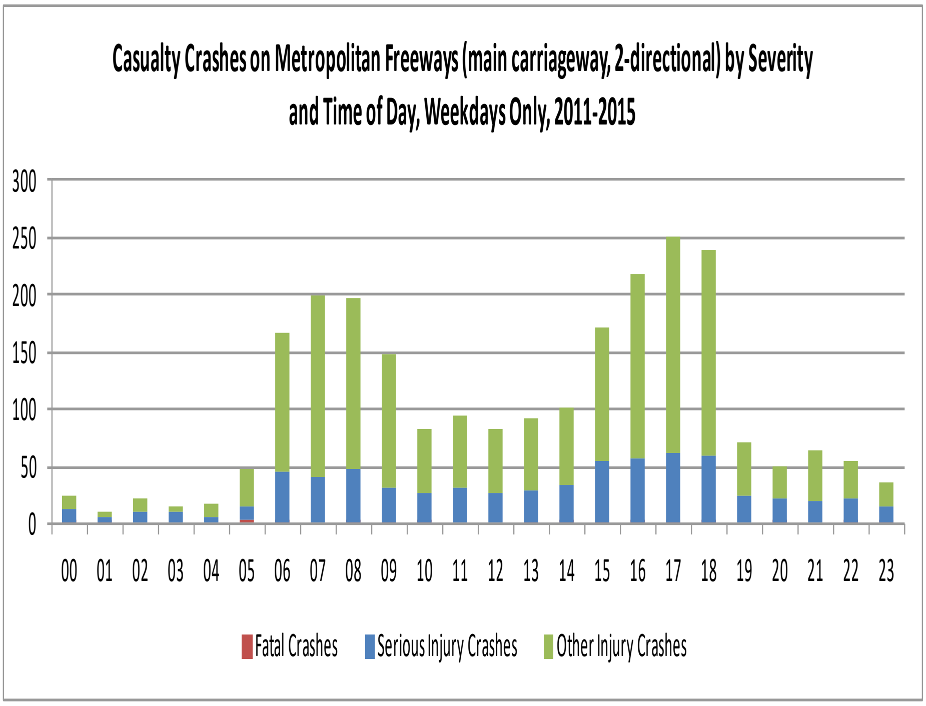

Figure 69 Casualty crashes on metropolitan freeways by severity

From (Yeo H, Jang K, Skabardonis A, Kang S, 2014) it clear the mixed result is mostly related to different "Traffic States" and possibly combined heavy vehicles mixes[200] which most researchers have not considered. Some studies use the posted speed[201] limit as an indication of average speeds, as when in the urban Australian capital cities this bears little relationship to measured speed profiles across the 24 hour day. The measured free flow carriageway speed over the day are typically 92-97km/h in a 100km/h speed limit zone and in peak periods these speeds reduce by 10-30% or more depending on congestion levels.

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[199] Research needs to consider urban motorways with higher percentages of commercial vehicles (i.e. 10-20% CV) as the when measuring crash rates with these dynamics speed may come in effect more then when commercial vehicle content is lower than 5%. When a heavy vehicle crashes in an urban motorway the outcome is often serious.

[200] The "traffic state" combined with heavy vehicles mix is a subject that has not been well investigated to date

[201] It is possible many road safety research reports have assumed speeds without collecting the raw data. The speed limit bears little resemblance of the actual speeds over the day on many roads and hence why crash data that measures impact speeds offers much insight and thus the need to undertake fundamental scientific research with actual empirical measurements from the field.

Also confusion often lies in researcher's definitions of peak periods which are no longer considered to be to be the traditional 7-9 am and 4-6pm and more likely in some parts of Australian capital cities to be 5:30 – 9:30am and 2:30 – 6:30 pm, hence road safety studies need to reflect the travel demands and that the shoulders of the peak are more likely to have the serious crashes (pre congestion "Traffic State", followed by the congested "Traffic State", refer Appendix C, Section 1.5 The problem of changing circumstance). Thus many older studies and some more recent studies which focus on the traditional peak periods are likely to miss the high crash numbers that occur on the shoulders of the peak due to their reduced scope of study to contain the amount of work as each crash record must be reviewed in detail, which takes considerably more time and resources to analyse.

16.8.1 Further research on safety, as a function of traffic states

Further work by (Golob T, Recker W. Alvarez V, 2003) has investigated crash rates and crash types as a function of eight different points on the Speed-Flow Curve refer (Figure 70 Explanation of various the "Traffic States"). The findings show that there seems to be a strong correlation between crash rate and the inherent "Traffic State" such as "Free Flow", "Synchronised Flow" and "Wide Moving Jam" (i.e. stop-start conditions) refer (Figure 71 Collision rates for each "Traffic State"). Crash rates with predominate crash types having also been plotted in standardised "space mean speed" and "median speed" versus variations in speeds between the slow and the faster lanes.

The predominate crash types change as "Level of Service" or density rises, for example, the crash rate can increase 6 fold with multi-vehicle accidents prevailing under "heavily congested flow" conditions. This effect identified by (Golob T, Recker W. Alvarez V, 2003) has also been somewhat demonstrated by the Before and After Study[202] of the Monash Freeway "Managed Motorway" where congestion has been reduced and traffic flow smoothed resulting in a 31% crash reduction over the 5 year periods measured before and after over a freeway length of 25.5km with 14 interchanges refer (Gaffney J, Lam P, Somers A, Boddington K, Johnston D, 2017). See also (Figure 60 Breakdown of casualty crashes by crash type by hour of day – Monash Freeway) to see the changing mix of crash types by time of day.

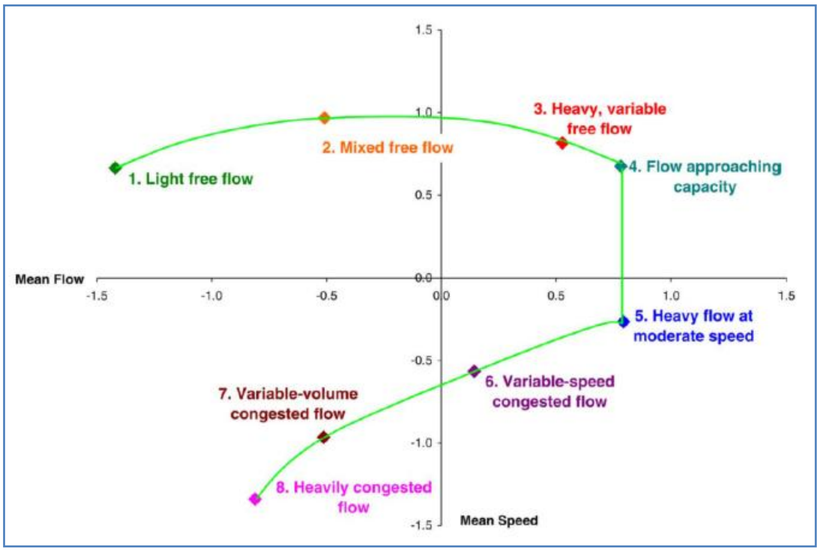

Figure 70 Explanation of various the "Traffic States"

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[202] Refer (Gaffney J, Lam P, Somers A, Boddington K, Johnston D, 2017)

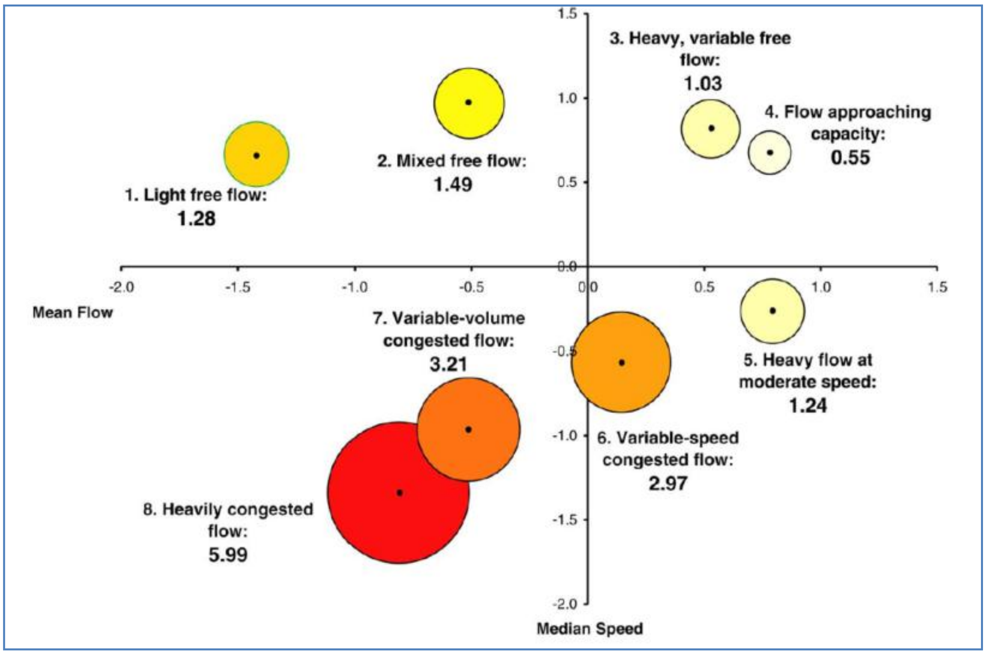

Figure 71 Collision rates for each "Traffic State"

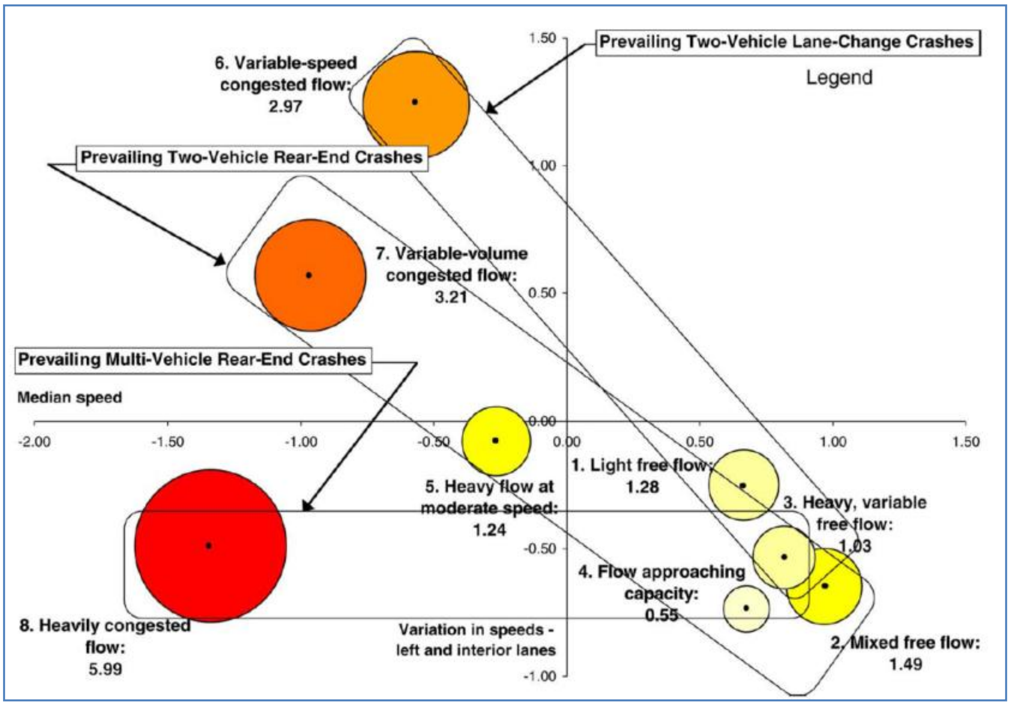

Figure 72 Estimated total rates per million vehicle miles of travel

16.9 Road safety practitioners must collect the detailed microdata

This research suggests that real-time crash risk may be able to be measured and that reduced congestion and smooth traffic flow are also likely to improve safety. It is important that Australian Road Authorities or Departments of Transport keep accurate disaggregated historical before data, preferable at 1minute intervals at the lane level, to ensure appropriate post analysis of crash causes can be undertaken before solutions are identified. Such studies will take time and effort, however, without this detail we will not understand the crash problem on motorways and many other roads.

Urban motorway crash research often is inconclusive as the traffic data collated is too coarse to draw any sound conclusions about cause and effect of individual crashes. For example, the traffic volume or speed profiles are often samples of weeks, months, seasonal or even annualised. Sometimes when daily data is available the day is broken down in to just a few periods (i.e. morning peak, afternoon peak, high off peak and low off peak etc) for analysis and, no attempt is made to find out what were the actual prevailing traffic conditions acting at the carriageway or lane level (i.e. point speeds), differential speeds (upstream and downstream of crash) or traffic volumes (+/-1mins or +/-5mins before and after the crash), traffic density/vehicle occupancy, vehicle type/mix, headways refer (Figure 23 Typical distributions of headways on an urban motorway), lateral position between vehicles refer (Figure 25),[203] lane changing activity, hourly Vehicle kilometres of Travel (VkT)) at the time of the crash.

Whilst some attributes of crashes are easily collected from police records (i.e. daytime/nighttime and wet/dry pavement),[204] the prevailing traffic conditions (e.g. perturbations) at the one minute resolution vary so significantly (refer Figure 56 above), that the causation mechanisms are usually overlooked in any crash analysis, yet are clearly discernible in traffic data sets. Very few studies have endeavoured to map individual crashes to actual traffic conditions even though in Australia this data has been readily available since the mid-1980's on urban motorways. Those studies that undertake the more robust analysis offer much more insight into crash causation and these findings are likely to lead to improved road safety practice and guidelines.

16.10 Safety as a function of traffic levels and number of lanes

With each additional lane on a freeway, the capacity per lane tends to drop (i.e. typically a 4% drop in capacity) as each additional lane is added refer (Hendrik Zurlinden, 2017) and most European Capacity Manuals. This phenomenon, although not acknowledged at this stage in the USA Highway Capacity Manual (USA Highway Capacity Manual, 2010), shows that the capacity reduction as more lanes are added is very likely to be substantially explained by the fact that the number of lane-changing events increase as conflict points increases with each additional lane added and, this additional friction, (i.e. "Lane Shear") lowers the per lane capacity refer (Figure 73 Number of conflict points in relation to Lane numbers) from (Kononov, Bailey, Allery, 2008)

One suggestion that has been made is that an additional factor may be that carriageways with four or more lanes have a greater mix of passive and aggressive drivers in their middle lanes resulting in greater uncertainty and friction within these lanes, refer AustRoads Guide to Traffic Management Part 3, Section 4.1 (AustRoads 2013a) which provides further details on capacity of uninterrupted flow facilities. Other researchers (e.g. German researchers) seemed to put the reduction down to heavy truck utilisation and maximum 80km/h speed limit of trucks restricted to the slow lanes. However in Australia, the same or similar effects are measured with trucks using all lanes and without specific speed limit restrictions.

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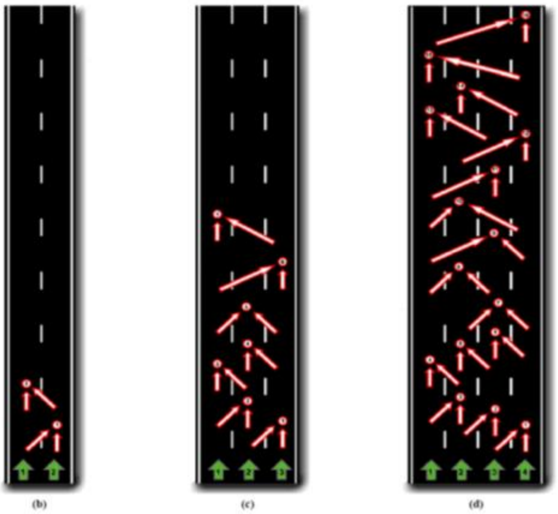
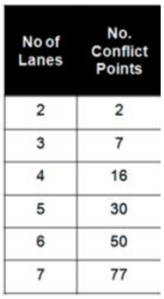
[203] Note motorcycles (blue dots) primarily travelling between the two fastest motorway lanes

[204] This may not be done particularly well refer (Najaf, 2012) The Little book of Tire Pavement Friction as damp pavements are often recorded as being dry.





No of Lanes	No. Conflict Points
2	2
3	7
4	16
5	30
6	50
7	77

Figure 73 Number of conflict points in relation to Lane numbers

Further research by (Kononov, Bailey, Allery, 2008) have described a link between crash rate and AADT, Levels of Service (LOS) and number of freeway lanes, refer (Figure 74 Changes in accident rates with AADT – APMPY (accidents per mile per year)), Figure 75 Six lane injury and fatal crashes: changes in accident rates and, (Figure 76 Relationship between lane numbers, AADT and Crashes (Accidents/Mile/Year)), (Figure 76 Relationship between lane numbers, AADT and Crashes (Accidents/Mile/Year)). This works shows that the accidents per million vehicle mile of travel for injury and fatality crashes tend to increase significantly between 90,000 AADT (0.24) and 120,000 AADT (0.38). Several direct quotations from (Kononov, Bailey, Allery, 2008) are included below.

Conclusions by (Kononov, Bailey, Allery, 2008) that *"**on uncongested segments, the number of crashes increases only moderately with an increase in traffic; however, once some critical traffic density is reached, the number of crashes begins to increase at a much faster rate with an increase in traffic.** This phenomenon is reflected by a steeper gradient of the Safety Performance Function (SPF). A high density of traffic in the high range of AADT is associated with approaching supercritical density and a levelling off of the SPF, reflecting a high degree of congestion and a reduction in operating speeds.*

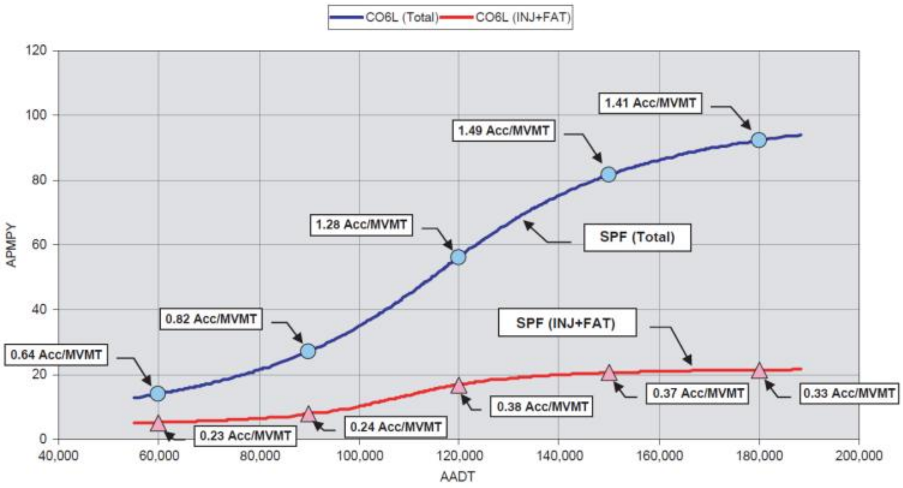


Figure 74 Changes in accident rates with AADT – APMPY (accidents per mile per year)

*“**Relating different Level of Service (LOS) during peak periods with accident rates within SPF shows that total as well as injury and fatal crash rates increase with congestion.**“*

*“**Understanding of the relationship between the LOS and the accident rate can be used to inform public policy, the transportation planning process, and highway design criteria**. This understanding offers an important insight into the relationship between safety and mobility that will improve the quality of decisions made by practicing engineers, planners, and elected officials.*

*Comparison of slopes of SPFs for different numbers of lanes suggests that adding lanes on urban freeways initially results in safety improvement that diminishes as congestion increases. **Once traffic demand goes up, the slope of the SPF, described by its first derivative, becomes steeper, and accidents increase at a faster rate with AADT than would be expected from a freeway with fewer lanes**. This is found to be true for total as well as injury and fatal crashes.*

*While more research in this area is needed, this phenomenon may possibly be explained as follows: **as the number of lanes increases, the opportunities for conflicts related to lane changes also go up. Furthermore, the increased maneuverability associated with the availability of more lanes tends to increase the average speed of traffic and the speed differential.***

*In addition to contributing to property damage and injuries, daily incidents on congested multilane freeways also adversely affect mobility. **The introduction of barrier-separated.... lanes are effective strategies to offset the increase of conflict opportunities associated with an increase in the number of lanes.”***

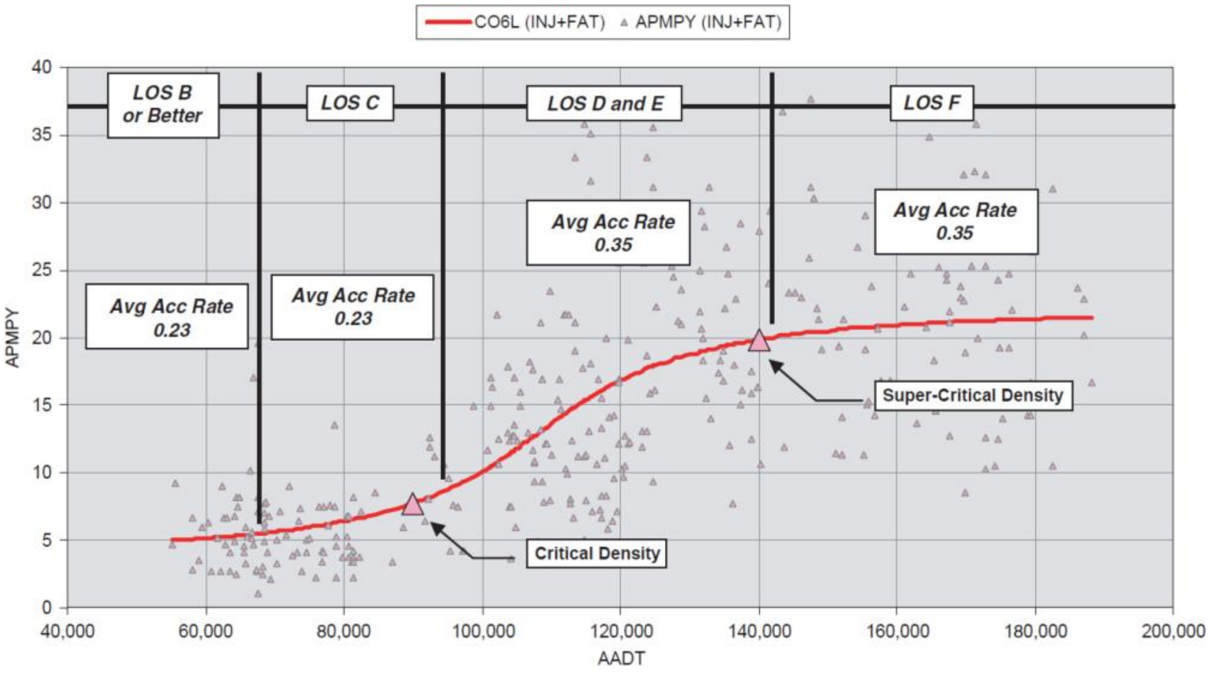


Figure 75 Six lane injury and fatal crashes: changes in accident rates

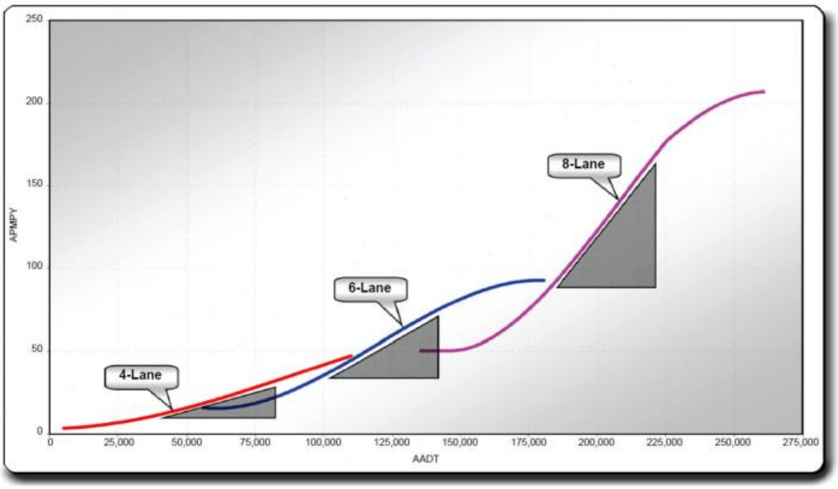


Figure 76 Relationship between lane numbers, AADT and Crashes (Accidents/Mile/Year)

16.11 Care interpreting road safety studies

When multiple studies are compared, often referred to as "meta-analysis" the basic tenet of these studies is that there is a common truth behind all similar studies so if studies are to be compared the trend or the average of similar studies will be meaningful. Some have argued that a weakness of the "meta-analysis" is that sources of bias are not controlled by the method as. "a good meta-analysis of badly designed studies will still result in bad statistics". (Wikipedia)

Hence, in this case, there is probably truth at both ends of the spectrum and since the pre congested and congested "Traffic States" end of the spectrum has not been as well studied, primarily due limited access to accurate historical high-resolution traffic data. Another problem is that road safety researchers are not necessarily trained in contemporary traffic theory to the level required to understand that traffic flow theory is no longer considered to be deterministic and, hence is considered to be stochastic with a certain probability associated with any outcome at any location as every section of motorway behaves differently and as every minute of the year is different.

Hence the complex higher traffic volume "Traffic States" which occur at the higher end of the traffic flow spectrum, where often the posted speed limit, have often been assumed to be the operating regime, and these studies have often dominated the road safety research and the road safety collective voice. Hence the louder voice by weight of research is usually heard rather than the small number of studies where there are much more detail and understanding of the complexity of the problem. That is focusing on the context (i.e. the unique factors that lead up to the crash), congestion levels, shockwaves, stationary queues, driver fatigue, rather than observable physical factors seen at the random crash location after the crash has occurred. As quoted by Albert Einstein, *"What is right is not always popular"* which could be interpreted to means that the larger the number of studies does not mean that they are right particularly since a "Black Swan" event has now been identified that would now place some "question marks" over the usefulness of many of these earlier studies.

Further work linking VicRoads motorway capacity analysis (Hendrik Zurlinden, 2017) refer (Figure 77 Breakdown and productivity plotted against flow rate (2 lane cross-section)) to (Kovonov, 2013) Figure 78 Relationship of speed, volume, density - LOS and total crash rates. It can be seen from these two figures that there is a general relationship between "Flow Breakdown" risk and the "Crash Risk". The author notes that when crashes are looked at more closely Level of Service F where the crash risk is shown to be high is not necessary the condition immediately before the crash (i.e. what occurs in the 5 minutes before the crash), however, it is the crash itself that often creates a flow breakdown event (i.e. LOS F) hence this is the reason why analysis of crashes is not an easy task to undertake. Shown in (Figure 21 Relationship btw Lane Occupancy and FSI Crashes - 5min resolution) above, the trigger point for many motorway FSI crashes occurs in the lower densities near the LOS C range (i.e. as measured by lane occupancies) and which then results in LOS F conditions. A second cluster of FSI crashes results from conditions relating to the higher LOS E range.

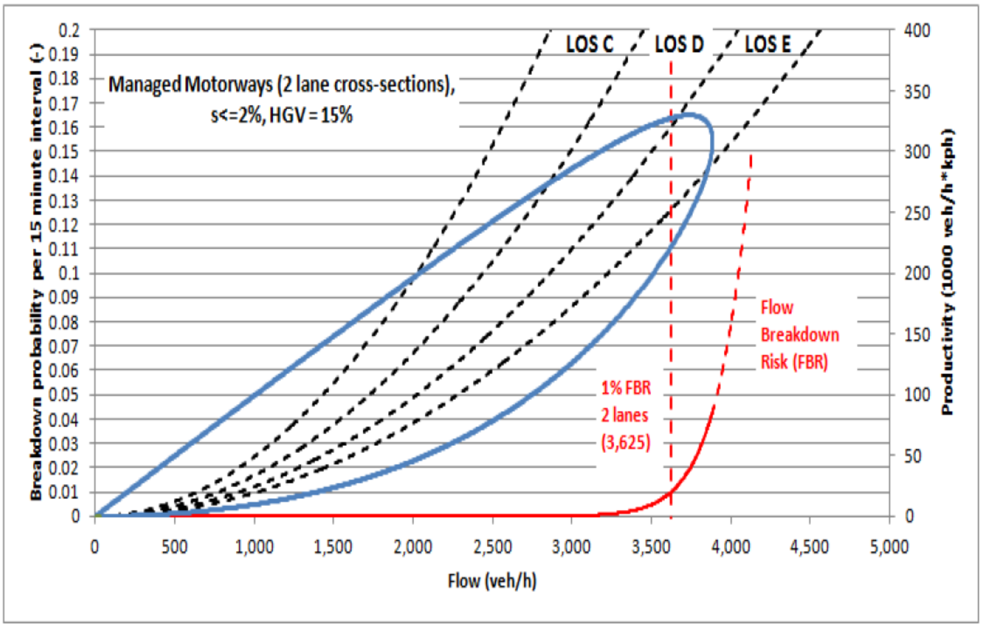


Figure 77 Breakdown and productivity plotted against flow rate (2 lane cross-section) - VicRoads

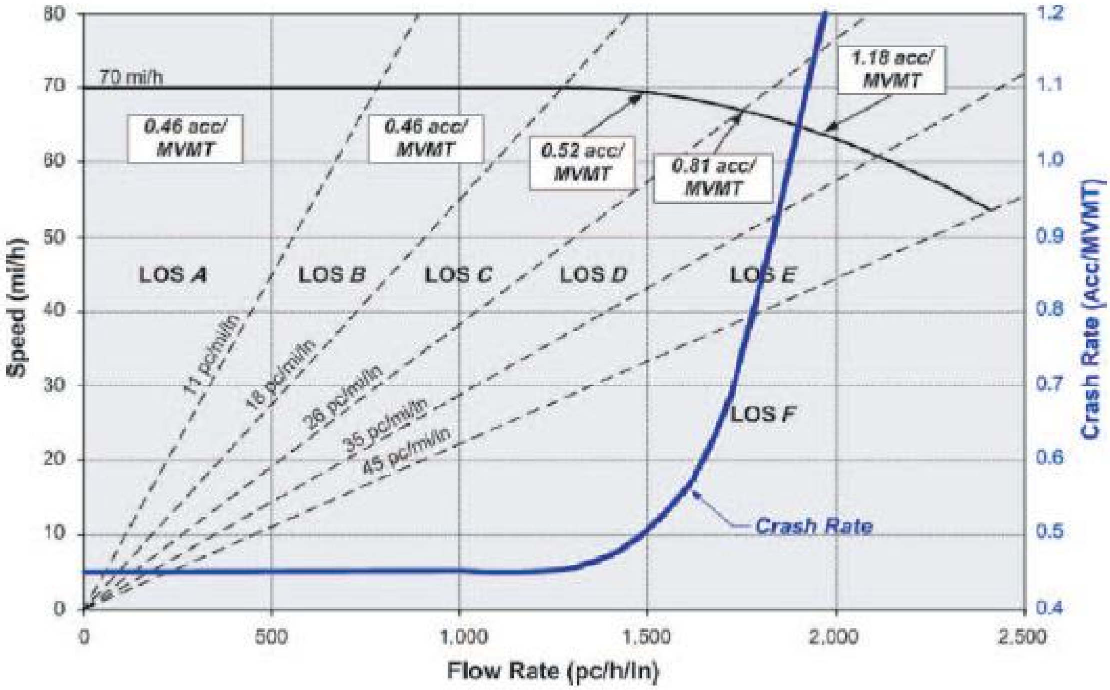


Figure 78 Relationship of speed, volume, density - LOS and total crash rates – J. Kovonov USA

17 THE INADEQUACY OF CRASH INFORMATION FOR THE CURRENT CRASH CONTEXT

Probably the most repeated theme during discussions was the need for better data on individual crashes and, the fact that context of crashes was changing such that traditional crash records were no longer sufficient to understand current problems. Another problem is that we have more road safety data than ever before in history and, at times we appear to be drowning in data (i.e. too much data) and, yet we don't have the means to process it. The analytical tools currently available are not deemed adequate to understand what the data reveals and often outdated metrics are being used which are no longer as useful for understanding the cause of most crashes.

Many researchers visited on the Churchill Fellowship identified the limitations of current crash data and statistics and the need for richer data required to understanding crash causation, particularly as each crash is a unique event. The current types of crash data collected may have been useful 20-30 years ago when there were obvious causes for the majority of crashes with a large number of similar crashes occurring in clusters (i.e. systematic), across the road network and which are classified into "Black Spots" and "Black Lengths". Now that more of the crashes appear to be random in relation to spatial groupings and more systematic in relation to other metrics (i.e. human error, fatigue, speeding and temporal traffic conditions), for which there is a lack of adequate data collected.

The current situation may relate to the fact that road safety historically emerged out of the civil engineering discipline (i.e. road infrastructure provision), and thus the data required to solve current day problems may not have progressed to the extent now required. The necessary accuracy of some metrics, the mathematics, statistical techniques, and rigour, required to eliminate randomness and bias has not been well understood or allowed for in the collection and analysis of data. We have not incorporated the collective requirements of vehicle engineering, behavioural science and traffic science in the data sets to the extent that it is now required.

An often repeated message from many discussions was that, even the data collected was often incomplete, often centered on the crash location, rather than understanding the human factors, the vehicle factors or the contribution of the temporal traffic or not obvious weather conditions (i.e. damp pavements caused by dew after dry weather). Recent insights into the complexity and diversity of crash causation have identified that more detailed crash data is required to be collected and analysed. In addition, when the crash causation changes (i.e. in the Netherlands) from a motor vehicle problem to being a major cycling problem on non-road infrastructure, the traditional crash datasets collected primarily for vehicle crashes no longer appears to be as relevant.

Additional data sets must include the safety and handling performance of individual vehicles involved in the crash, the context for the pedestrians and cyclists, for example, did they have a clear view of the road, and in the case of remote area rural crashes, many which are on local roads what were the unique conditions[205] involved in the moments when each crash occurred, (i.e. the actual traffic and weather conditions at the moment of the crash and the unique circumstances that lead up to every individual crash). This includes details of the drivers past 24hrs or possibly up to seven days of activity as has been necessary to assess OH&S issues in Japan for employees involved in workplace incidents.

Unless we study in fine (micro) detail all vehicles involved in all crashes and interview survivors, without prejudice, to understand the unique circumstance in which the crash occurred, we will

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[205] Could there have been a kangaroo that hopped across the road that would never have been observed or reported in fatality crashes however this would be identified from interviews with casualty and property damage crashes and solutions could possibly be developed.

continue to lack understanding of crash causation and continue to have high crash rates with more casualty crashes and serious injuries. Heavy reliance on historical police crash records alone is no longer considered to be adequate, given each crash has a unique vehicle, unique driver and unique circumstance and, it is at this more detailed (micro) level that crashes need to be individually investigated rather than in geospatial groupings (macro thinking) of all crashes as a fixed point or a location (i.e. route) specific problem. Thus road safety needs to be considered more as a complex system (wide) problem rather than a spatial point or route problem, where historically the majority of crashes occur at fixed locations with known problems with relatively simplistic and standardised interventions.[206]

17.1.1 Are traditional crash records by their nature skewed or biased?

It may be that some our crash records are skewed based on distance from police stations as many rural crashes are dealt with by informal processes without police or tow truck involvement. Even the minor or serious injury crashes the local residents or other drivers may drive a victim to hospital some time later and never involve the police. The only crash records that may be free from bias are fatality crashes as these must be reported to police. Fatality data therefore may give us insights into the bias of other crash records when we look at their distributions or patterns to better understand the true random nature of many crashes.

Evidence in the UK has shown that over the past decade police records under report injury crashes by a factor of 3 to 4 compared to hospital records and hence in the future, (i.e. from 2017), they will be changing their published road safety reports to correct this deficiency. Thus if we only investigate a sample of crashes (i.e. one-quarter of the crash problem), there can be no guarantee we have a representative sample of all the factors involved in the problem. Our current approach also has masked for too long that the road safety problem should now be substantially recognised as a system-wide problem where the focus of road safety must be on avoiding all crashes whenever and wherever they occur, as the outcome of any crash cannot be guaranteed.[207]

17.1.2 Statistical crash hot spots through circular thinking

Discussions in Europe revealed there may be a form of circular arguments at play, where on average police reports may only represent a small percentage of casualty crashes (i.e. 25-30% as in the UK), as this is all the police see or get notified of and attend. The circular argument then becomes as follows; where there are high numbers of crash reports due to vigilance of certain police officers or police stations this can lead to higher focus of road safety effort and more resources applied in that region (i.e. police sometimes get paid overtime for additional traffic patrols),[208] which in turn results in higher levels of enforcement which in turn results in more crash reports being written. A diligent police officer is likely to encourage crash victims to get checked out straight away by a doctor or medical centre thus a hospital or medical record is generated further skewing the statistical evidence.

This approach to enforcement often tends to catch nonregular road users (i.e. unsuspecting outsiders or tourists), as the locals soon "Learn from Exposure" (Elvik, Elementary Units of Exposure,

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[206] A number of these many crashes may just have been classified based on patterns created by humans as this is how humans typically understand or communicate complex problems

[207] refer AustRoads report SAG2090 which quotes "*crashes in Auckland, New Zealand, where in 2013 79% of the fatalities and serious crashes occurred at sites with no fatal and serious crashes in the past five years, and 64% of crashes occurred at sites with fewer than two injury crashes in the same 5 year period*".

[208] Regular overtime pay can be a valuable source of extra income and to sustain this as being effective more infringements notices must be written further increasing bias.

2009) and, they know where the local cameras or radars are or where the police officers regularly enforce. Due to the diligence of the police officer a higher level of crash reports are prepared which enter the road crash databases. This then, in turn, results in reinforcing crash “Hotspots” which results in the additional focus on effort, funding or resources being provided to do more enforcement and this, in turn, increases infringements and fines.

Thus increasing the typical 25-30% of casualty crashes reported on average to a higher percentage (i.e. an extra 10-15%) means that we may see a statistical crash “Hotspot” in certain areas and apply more road safety money to that region. Such activities skew the data and where resources are allocated and hence crash “Hotspots” tend to remain “Hotspots”. Simple statistical methods could be used to measure and eliminate this bias in the data and corrected to normalise police records before scientific analysis is undertaken. Such problems can be easily identified and corrected by use of statistical methods, however, is this being done with current Australian datasets?

17.2 Crash investigations need to understand the driver’s perspective

Much more insight is needed to be gained from new data sources such as understanding the driver’s perspective, what circumstances lead up to the crash (i.e. tiredness, busyness, distractions, the vehicle type and design) and, this data also needs to be linked directly with external databases that show the actual traffic conditions and weather conditions (i.e. dew point [209]or pavement temperature, at the time of the crash.

As discussed above on urban motorways, traffic conditions are the main precondition to the likelihood of a crash event which for too long has been overlooked by researchers and analysts who are often not well trained in the field of traffic science. For example, due to the oscillatory nature of congested traffic, the cause (trigger point) of the oscillations is usually occurred well downstream of the crash site usually hundred’s of metres and often several kilometres and are known to be up to 5km or more downstream. Hence, traditional crash investigations generally only look locally in the vicinity of the crash site to identify local road features that may have contributed to the crash in order to provide treatments. Thus many treatments are funded which may not directly relate to the crash cause.

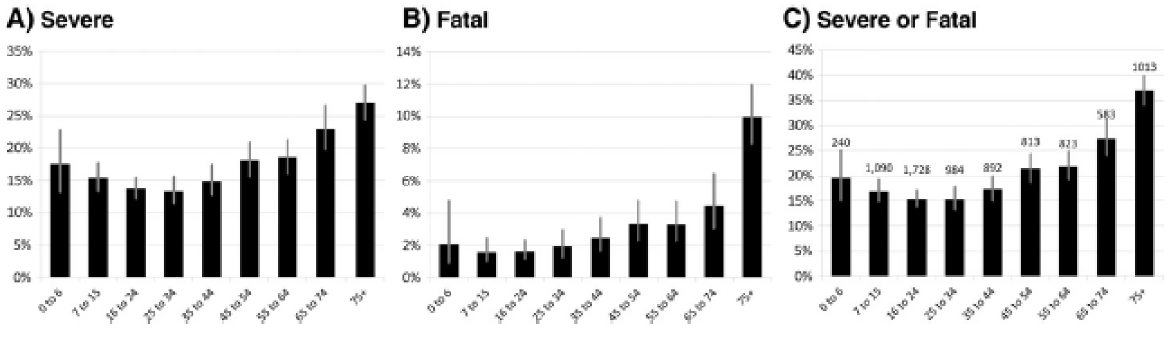

Fig. 4. Risk of A) severe injuries, B) fatal injuries and C) severe and fatal injuries by age groups for dataset 1. Confidence intervals (95%) are based on [37], and the numbers in panel C show the number of observations within each age group.

Figure 79 Pedestrian crash risk is highly skew towards the age

The very detailed crash investigations carried ay BASt, Germany over the past 18 years discussed below are revealing many new insights in the crash problems including vehicle design deficiencies

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[209] Potentially the “dew point” can be linked to pavement friction and pavement temperature is a unique safety issue for Australia where friction is reduced on hot pavements i.e. pavement temperature greater than 50degrees C.

and methodological problems such as, sample bias (Erik Rosen, 2009) which leads to over simplistic and inappropriate findings. In (Erik Rosen, 2009) the results showed ***when sample bias is not present, far lower fatality risk than generally reported in road safety literature which in turn must lead us to new understanding and new directions***. Such is the paradox where FSI crashes in the 30-50km/h zones are fast becoming problematic in parts of Europe and possibly in Victoria's "Grey Spot" program in shopping centres particularly when age of victims is taken into account (Kroyer, 2014) refer (Figure 79 Pedestrian crash risk is highly skew towards the age) above.

17.3 We need to understand human error or human frailties

All drivers routinely make mistakes both small and large and generally they get away with it as other critical factors (i.e. the Swiss cheese model), do not align and, generally as other drivers see our mistakes and adjust their driving accordingly. **This means that most drivers do not get feedback when they make mistakes as other things compensate to avoid a crash as usually other drivers see the mistake and automatically react to avoid a collision and do not give any signal to the offending motorist (i.e. tooting the horn)**. I don't know how many times I have driven on a country road over the years and someone overtaking coming towards me has misjudged the task and, I had to slow down and/or pull off the road. This is a very common problem occurring on our roads, yet we don't seem much better in 2017 than more than 50 years ago in 1967 at solving this problem. Very few road safety research reports discuss such human behaviors (i.e. human's assessment of risk is often poor).

Because of this lack of feedback on one's own driving skills a crash often comes as a complete surprise to the motorist because they consider themselves a good and safe driver as up to that point they have avoided crashing their vehicle despite making many mistakes. Another issue that arises is when a driver is confronted with their bad driving, is the driver willing to change their driving behaviour? There was strong agreement that human error will remain and there are now many vehicles aids to support the driver with another set of hands, eyes, and ears etc. and these are considered important to have deployed in our vehicles today rather than in 10 years time. In addition, there were many things we could do from a road design point of view and thus a good technical resource recommended is Designing Safe Road Systems a Humans Factors Perspective (Jan Theeuwes, 2012)

Since "human error" is known to be the cause of most crashes it becomes obvious that our data sample size is very small compared to the scale of the human error problem. It may have been naïve or even a mistake in the past to stop collecting "property damage" crashes as behavioural scientists believe it is now considered necessary to be interviewing more drivers involved in crashes to understand contributory factors that led up to the crash, refer Figure 80 Indicative crash-related data in relation to human error, which attempts to show we do not really collect much data on human error which is the main contributor to the road safety problem. By comparison to some of the European countries, Australia collects very little of this data (e.g. the long-running -18+ years BASt GIDAS study)[210][211].

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[210] While it is acknowledge there may be similar studies undertaken in Australia, preliminary reports may suggest the findings thus far have been limited

[211] It is acknowledge there is a Monash University (MUARC) Enhanced Crash Investigation Study which is soon to produce an interim report, however after visiting MUARC it appears this study is limited and more selective in crash investigations than the German GIDAS project and thus is focusing on samples which relate to the higher end of the crash distribution ad may not therefore be representative of all SFI crashes .

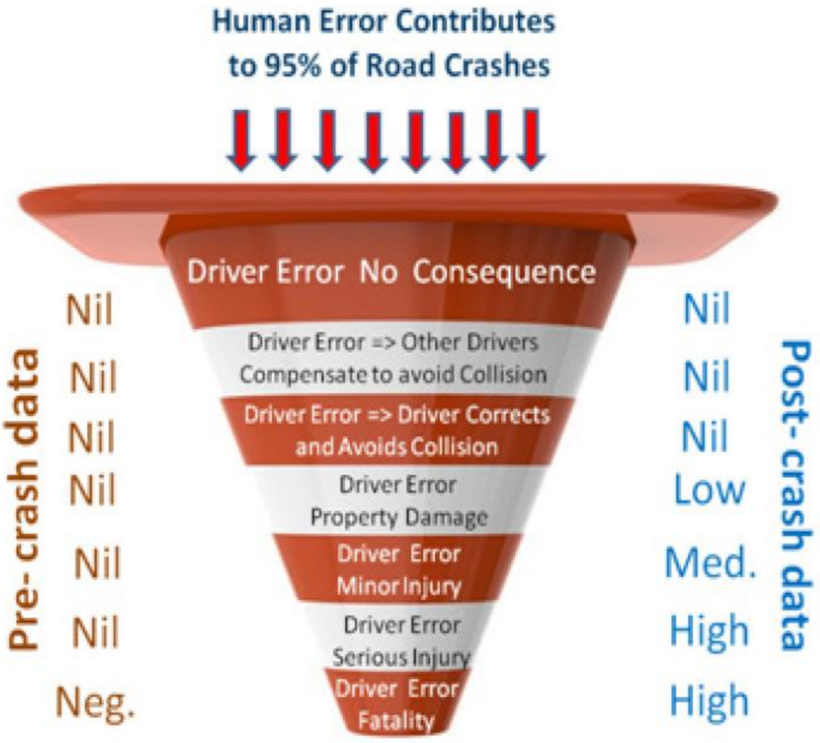

Figure 80 Indicative crash-related data in relation to human error

17.4 All crashes must be reported in some way, shape or form

When crashes are clustered spatially in relatively small numbers (i.e. less than 5 crashes of a similar type within a 5 year period), this may be strong evidence of random clustering crash rather than the actual location being specifically dangerous. Thus larger samples of crashes from other sources including insurance records, tow truck allocation,[212] hospital records and written-off vehicles registers are also required to collect accident location data to increase the sample sizes which would help further distinguish whether crash problems are random or systematic. This may change our collective thinking towards road safety being a substantially system-wide problem where safety must travel with the driver and the vehicle, rather than the current emphasis which is largely towards being infrastructure focused[213].

Thus it is considered timely to revisit what crashes should be reported and included in database records as discussed below in the Section titled “The Luck of the last 150mm” being the difference between a bruised shoulder which potentially has no police report as the bruise occurs the next day, or a fatal head injury or fatal injury to a vital organ in a road crash. We can no longer ignore the fact that the cause of most non injury crashes is same as the cause and circumstance of most FSI crashes. These crashes need to be recorded even if less detail is captured or other sources of information are used, such as improved tow truck allocation information,[214] more accurate data captured through the “written off” vehicles registers or greater use of insurance records etc.

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[212] In rural Australia tow truck allocation data is not useful as processes to recover crash vehicles and convey victims to receive medical treatments are often informal as necessitated by the remoteness and practicalities. If any speeding or other law breaking activity was involved there may be little interest in advising authorities.

[213] When analysed on the bases of resources allocated and budgets expenditure

[214] Informal tow truck arrangements often occur in rural areas where crash numbers are rising

Thus focusing solely on FSI crashes for many years has been convenient and cheaper nevertheless they are no longer adequate to understand and solve the increasing crash problem across Australia. This is particularly the case on urban motorways where there are many crashes but only a few actually get a police report as no injuries are involved and hence the problem of traffic high traffic volumes and congestion causing FSI crashes has been overlooked. Australia is spending $M100's on road safety per annum hence spending more money per annum (e.g. $M's (1%)) on capturing more detailed data is considered to be a sound investment. To solve the road safety problem all crashes must be reported, including their location, in some statistical way, even if secondary means are used such as insurance records or "written off" vehicles registers which in Victoria contains more than twice the number of records as police records (i.e. 50,000)[215] per annum.

Rune Elvik TOI in particular and other researchers, identified real concerns about the quality of the police records particularly since computer automation of coding with little or no manual checks by experts who understand the logic of traffic and road crashes or the context (i.e. understanding) behind the database coding. The main concerns were erroneous data and incomplete records. This also became obvious in Victoria where the motorway crash statistics were coded with may many obvious errors for example as having "dawn" which should be sometime near daybreak coded with a time stamp at 10 am in the month of January. Also motorway crashes such as sideswipes may be just that, or may have been what a driver did to avoid a rear-end crash, hence some interpretation of the written police report is required to understand the actual causation mechanisms involved and this information is not revealed at the macro level of crash data that most analysts use. Most analysts are generally not looking for this level of detail as they have not be taught the relevant traffic science.

Discussions with VTI Sweden, BASt and Ruhr University in Germany expressed concern that independent interviews (i.e. independent of police authorities), for fear of prosecution are necessary. These are considered necessary for all serious casualty crashes to understand the context before the crash occurred. Such interviews would seek to establish the driver's: tiredness, anger, aggression levels, attitudes towards speeding, assessment of their driving skills, beliefs, attitudes to other drivers and their level of self-confidence etc. "Rear end" and "sideswipe" crashes may occur under similar circumstances, yet are classified separately even though sometimes the difference in classification from the measurement of the impact zone is only a matter of centimetres.

Police records often will only tell part of the story and our understanding the crash cause may often be masked if some sort of potentially illegal activity was involved, or some breach of a road law occurred (e.g. speeding, disobeying a road rule) or a reluctance of the public to be open and honest with the police authority as they might find something else to pick them up on with an expensive infringement notice which is a common position in Australia. This is particularly relevant if past experiences with the police have been negative which may have become more noticeable in recent decades because of the rapid rise in recent years of the high number and high cost of infringements for in the view of public's opinion are for relatively minor indiscretions that many motorists do not relate to as being serious road safety outcomes. Over use of enforcement can reduce its effectiveness when public opinion no longer see it as being effective, such as in Australia where it I likely that independent market research would reveal many infringements are a form of taxation as often technology does not understand variable contexts (e.g. at intersections where the turning vehicle gets caught and which may not be the one at fault as a very late vehicle accelerated and

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[215] Vehicles written off by crashes only. There are other reasons to right off vehicles (i.e. flood, fire hail etc).

entered the intersection from the opposite direction forcing the committed[216] driver to make a split second decision where it is impossible to avoid a fine or else stopping and create another bigger safety issue of remaining in the intersection until the next cycle is completed.

Thus the road safety narrative discussed in Appendix C, Section 1.6, The problem of simple explanations, may be wearing thin with the public. One person mentioned whenever they drove in Melbourne where there is a red light speed camera they got anxious because of receiving what they believed to be an unjust and expensive traffic fine for something that was safe and fractions of seconds split the difference between receiving a large fine when the camera is unable to understand circumstance or context.[217] Hence they said they were more likely to react inappropriately and brake suddenly and may cause a crash behind them when the lights suddenly change. This is an unexpected outcome and may explain the Australian reports by leading road safety research centres e.g. (Andreassen, 1995) (Sally Kent, 1995) & (CN Kloeden, 2009) discussed above that did into find a statistical basis for red light cameras[218].

Some behaviours which are difficult to interpret also seem to occur around speed cameras sites on urban motorways which is clearly evident in the crash data when combined traffic speed and density data. This is discussed further in Section 14 (Motorways Speed Management for Efficient and Safe Operations).

17.5 Time for a rethink of how road crash information is collected

The key message from the Netherlands also relevant to Australia is they suffer from poor road safety information including police and medical records with the typical response being the police are being overworked and under-resourced which means police have other priorities and many other forms to fill out besides road crash forms. This seems to be the case following discussions with police officers in Victoria who also have other forms to fill out especially if minors are involved in these incidents.

It appears in the Netherlands single driver "run off the road" fatalities are of no real interest for the police to investigate as the cause of the crash appears to be cut and dry. Yet we need to know much more about these types of crashes which occur in high numbers. There seems to be a lack of detailed information in the Netherlands, as the police registers seldom identify the cause of many crashes.

17.5.1 Improving the Safety Data Collection Processes

An observation would be that the paperwork and time involved and the processes are outdated for collecting good crash data at crash sites efficiently. It is timely too in Australia that a "time and motion" study was undertaken of the police forms and processes and that this be combined with a systems engineering approach to ensure the police can process the information in less time and with more details using modern technology (i.e. a phone app with high-resolution images) and coordinates, time stamps that link automatically to weather conditions and, traffic data, images of the crashed vehicles are important and driver licenses scanned and data automatically populating

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[216] committed mean already entered the intersection before the red light camera activates and their tow bar triggers camera

[217] Many examples where an intersection red light camera can catch innocent drivers unaware as another driver has made the mistake of running the red from the opposite direction leaving an innocent and responsible motorists stranded and their tow bar crosses the stop line a fraction of a second too late. Is this process being independently audited from an independent source with adequate technical qualifications and training?

[218] An analysis of CASR 2018 report on crashes at red light camera sites seemed to have conclusions not related to the report's findings – the analytical work implied none of the answers were significant yet the conclusion strongly supportedthe current agenda despite evidence showing increased number of crashes.

the database without manual input. Hospital records and "Written off Vehicle Registers" should also be traceable to the general crash location or road name/suburb and dated and linked to existing crash databases.

Also, the "written off" vehicles registers should form part of the true crash statistics and analysis and location data should be included where possible including drivers/owners address. Note that people do not necessarily want to stay around at the crash site any longer than necessary and deal with process of the police report. It might be appropriate, for example, that all crashes where an airbag is deployed are also reported with an online form before they are allowed to be officially registered as written off. More data is required on the actual reason and locations where these vehicles are "written off".

17.6 Inadequate datasets for post-crash analysis

The limited datasets only collecting details when people are injured are now considered to be missing much of the detail as to why crashes occur. The practice of not collecting details of property damage crashes may have been a good economic decision back in the 1980's when Australia had many truer "Black Spot" sites to investigate and make safe. However times have changed and we are no longer content with the current state of the road toll and if we want to bring the road toll down further, methods have to change and more information and understanding of the crash causation is required. No two crashes are the same and human factors are involved in approximately 95% of crashes. Most of the human factors information can only be collected from interviews of all those involved on a wider range of crashes including "property damage" crashes.

17.6.1 The Luck of the last 150mm

When the human body is subjected to a vehicle crash the distance on the human body between the shoulder and the brain is only about 150mm. Hitting the top of shoulder hard during a crash event might leave only a bruise which may show up for a few days later, however hitting the head with the same force near the temple might result in a fatality or a serious brain injury. Hence logic and physics suggest the final 150mm is to a large extent comes down to luck (i.e. random chance) as to the crash outcome. Hence the current practice needs to be reconsidered now that vehicles are much safer and many more crashes do not involve immediate or obvious injury although people may attend hospital or a doctor sometime later. We must study and know the causes of all crashes if we are to reduce FSI crashes further.

Knowing the crash causation will involve interviewing all people involved independently of the police and examining the vehicle, the crash location and assessing in details the extent of the vehicle damage including recording the vehicle's computer details at the time of the crash (i.e. impact speed and tyre pressures if available). This has been the case at BAST in Germany for over 18 years and the database developed has very rich data and is leading to new understanding of vehicle design and deconstructing long-held beliefs and myths associated with road crashes (i.e. impact speed and speed zones) might not show a strong relationship as impact speeds in 60 - 80km/h speed zones might not vary much from those occurring in 130km/h speed zones. One of the key findings of the GIDAS BASt study is the small sample sizes used often biased as decisions have been made not to collect data on all crashes and/or to use all the data. Instead, they selectively use (i.e. from hospital trauma units) only certain FSI crash data which skews the answers significantly and thus often supports the narrative.

17.6.2 Risk-based data

The future direction seems to be about collecting risk-based data as a study of one highway in the Netherlands revealed 83 obstacles in the clear zones 27 crashes hit obstacles (i.e. small trees that grew into large trees and large trees can kill). Was this a maintenance issue or a design issue and thus are “clear zone” safe if they cannot be well maintained as even debris (i.e. a small rock or small log, or small variation in the ground surface caused by rubbish or erosion), can flip a vehicle travelling at speed. Examining practices in Europe it would seem that guardrails should be provided on both sides of motorway carriageways and this feature other managed motorway tools should be the standard and be a higher priority than investments other roadside features such as architectural or landscaping features which often seems to be the case in Australian urban motorway projects.

18 ARE THERE LIMITS TO ROAD PROGRAMS, MEDICAL SCIENCE, AND VEHICLE TECHNOLOGIES?

Is it possible that the combination of road safety programs, safer vehicles, improved medical intervention, improvements in the emergency medical intervention (i.e. emergency services offering “life-saving” treatment in the field) cannot advance at the same rate as we have seen in the past 30 years? The results of the past 30 years have been quite remarkable and may be difficult to sustain, particularly as crashes will continue to occur remote from hospitals and medical treatment. Telecommunications is now almost ubiquitous with little likelihood of further rapid advancement as it currently offers an almost instantaneous connection to Emergency Services and, vehicle design may be approaching similar limits of physics and, material science may have reached a threshold with respect to occupant protection.

All these sectors which have been key factors in road safety field have been able to collectively keep pace with the growth in vehicle numbers and travel and enabled us to bring the number of fatalities down against the rising growth in transport demand. However, can the progress made over the last 30 years be sustained into the future without further scientific breakthroughs? Despite this great success, **it is still very likely that in the next 30 years the greatest potential for improvements in road safety will still come from the involvement of these same sectors continuing to work together and potentially much closer together than in the past**.

The current slowing of road safety progress might be to a large degree our limited ability to recognise contextual change and being slow transitioning, at least a significant portion of our road safety effort, towards technical solutions that focus on avoiding crashes (i.e. prevention), rather than substantially focusing on infrastructure improvements to reduce the impacts of crashes once they occur (i.e. cure).

18.1 Are their limits to “Black Spot” and “Black Length” programs?

Various thresholds and limitations may now be emerging where some road safety programs may no longer be as effective as they once were. For example “Accident Black Spots” historically had large numbers of crashes of a similar type at a single location. Due to a large number of crashes of similar types, these locations were considered to have a low level of randomness associated with crashes. Hence “Accident Black Spot” treatments were very effective. Over time the numbers of similar crashes at any fixed geographic location have reduced significantly. This is primarily due to the effective targeting of road safety “Black Spot” treatments over many years and, road safety audit programs improving the design of all new road construction and, improvement projects (i.e. widening pavements and sealing shoulders and remodeling intersections) as well as improvements generally to road design and maintenance standards and practices.

Consequently many “Black Spot” sites now have much lower crash numbers, which introduces the issue of whether small crash clusters of different crash types suggest statistically that these should be considered to be more random statistical clusters which chance alone would also display similar patterns or distributions with small samples from only 3-5 years of crash data. Hence if randomness is involved “Black Spot” treatments will generally show improvements in road safety “after study” analysis whether they were correctly targeted with appropriate treatments or not. This is due to the fact events that are outliers (i.e. sites with a high occurrence of crashes) usually return to lower crash numbers, closer to median values when samples are taken in the next period (i.e., in this case, the following after period when the analysis is done). Also “Crash Reduction Factors” that was applied in past decades to certain treatment types may no longer be relevant as these were statically based on large numbers of similar crashes occurring at crash sites. Treatments of crashes along routes (i.e. ”Black Lengths”) cannot therefore adopt the same or similar crash reduction factors as “Black Spots” and the nature of the crashes and the problem varies and is so different that the crash risk is much lower compared to the benefit and will result in quite different outcomes and thus when new programs are developed the science and the benefits needs to be reestablished so that new crash reduction factors can be developed and updated on a regular basis (i.e. updated at least every 5 years) as context for transport is rapidly changing and so must road safety programs change.

18.2 Is there a response to the current limitations of safety programs?

Because it is almost impossible economically to make the entire road network safe, the future of road safety programs needs to consider safety that moves along the road with the vehicle by providing the driver with:

- another set of eyes and another set of hands via warnings and automated vehicles interventions e.g. Electronic Emergency Braking (EEB), lane keeping, blind spot and fatigue monitoring etc.

- applications that avoid collisions and keep the vehicle operating within known safety limits (i.e. matching speed to actual (temporal) pavement conditions) such as surface type and other road conditions such as rough, wet, hot and damp pavements, and road geometrics by offering warnings for overtaking and passing etc.

Hence Road safety programs may be better focusing more effort on vehicle-based safety applications that travel with the vehicle and the driver, such as collision avoidance, fatigue monitoring, lane keeping, automatic emergency braking systems. Considerations should be given to mandating 5 Star Crash ratings as well as introducing the European emergency management system to connect road crashes and breakdowns instantly with emergency services (e.g. Ecall and BCall) to further reduce emergency and vehicle breakdown response times.

These later two road safety applications Ecall and Bcall were first included in the 2007 EU Directive 2007/46/EC and are mandatory in all new vehicles from 2018 in Europe, refer Figure 81 below. This is an example where Europe recognised the importance of the emergency medical services, emergency services, the vehicles industry and telecommunications as being responsible for saving lives and reducing the impacts of road crashes due to early intervention when a crash occurs, refer Appendix A (An alternative perspective on the road safety narrative). It would appear that whilst some sectors of road safety in Australia have raised this issue, it has not so far become a serious contender in road safety strategies. Even though many vehicles in Australia which have been made in Europe and Japan may have these systems already installed in their vehicle but not activated and despite the fact that Australia has a serious rural road problem with many crashes occurring in remote areas which would immediately benefit from such an initiative.

18.3 Breaking through this temporary interruption to road safety

It is logical to assume in the short to medium term, the Australian population will continue to increase and that travel demand per capita will continue to rise. There will also be a commensurate increase in numbers of older drivers, pedestrians, and cyclists. This will combine with the increased complexity that comes with higher traffic volumes, on roads with more lanes requiring more complexity to drive, as well as the continuing problem of human frailty. With regards to traffic flow on motorways when they are placed under significantly more stress they will not gradually get worse they will actually break down more often with traffic throughput losses often by as much as 50%

and, which further accelerate crash risk as well as extending the duration of the peak period where conditions are more dangerous.

Figure 81 ECall mandatory in all EU vehicles from 2018

One “Event of Exposure” that rapidly increases during flow breakdown conditions is the extent of lane changing activity which has been measured to double, refer (Figure 82) showing the lane changing movements rapidly increasing immediately after flow breakdown event sets in,[219] as motorists seek to gain an advantage. A commonly measured background lane change rate, in heavy but noncongested conditions, is in the order of 2000/lane changes per kilometre/hour. Therefore it is rational logical and convincing that under the current trajectory of circumstance and current direction of road safety strategies there is likely to be an upwards growth in the numbers of crashes some of which will be FSI crashes until new solutions are identified that can be implemented to address these increasingly harder road safety problems, for which to date we do not have many such solutions readily available (i.e. “on-the-shelf”).

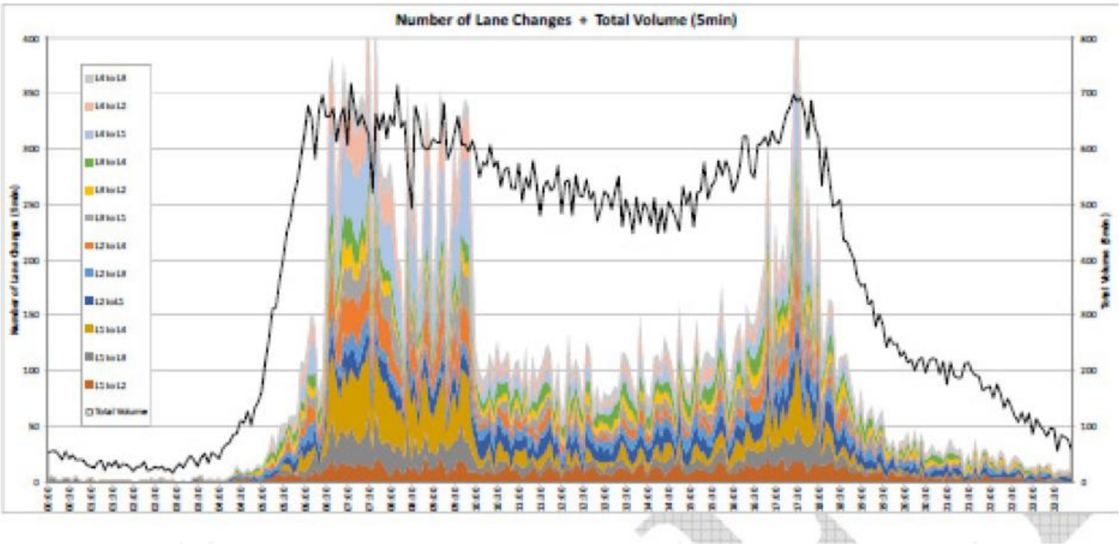

Figure 82 Stacked histogram showing individual lane movement combinations (5 min)

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[219] Note other factor may be contributing to increased lane changes such as random fluctuations or rapid changes in origin –destination patterns which can be observed by rapid changes in downstream exit ramp volumes in response to business activity.

The road transport context is rapidly evolving due to the impacts of mode shifts towards walking and cycling which are more vulnerable forms of transport and, which potentially create increased risk due to increased numbers of these roads users. A possible consequence of increased use of public transport is likely to be increased exposure to walking (e.g. to and from stations or stops), which has significantly increased over the past decade. Hence are we measuring walking and cycling exposure accurately enough to measure the link to increased pedestrian and cyclists crashes as is being done in the Netherlands? Since crashes are rare events we will continue to see crashes in the lower speed limit zones (i.e. 30-50km/h), since most crashes 95% actually occur below 39km/h refer (Table 7 Energy Equivalent Speed (EES) from a sample of crashes 1791 where impact speed could be determined).

Hence incomplete attribution and slow adaptation of how different road safety initiative’s benefits are claimed in a world that is continually changing is likely to be one of the key reasons why the Australian road toll is no longer reducing or at least reducing at the same pace of the past 30 years. Breaking through this hiatus requires recognition of our collective human “blind spots” or shortcomings and putting in place systematic and scientific (evidence-based) processes and acquiring the relevant expertise to guard against these limitations moving forward. The Road Safety movement may well benefit from an independent (i.e. by those not aligned to traditional perspectives) group of scientists from unrelated disciplines (i.e. physics, engineering, mathematics, medical and behavioral sciences) to ensure we remain objective and our eyes remain open to the best possible evidenced based thinking and solutions Australia can provide.

As discussed in (Wegman F, 2015) relating to “evidence-based” and “data-driven” road safety management and project evaluation of specific road safety treatments:

“It is evident from the description of the evaluation work that a substantial amount of assumptions needs to be made in the process. Key assumptions related to extrapolation of past trends, of penetration levels and of the effectiveness of new policy measures. ***A complicating factor with regard to new policy measures is that policy plans often discuss broad actions rather than specific measures****. As a result, assumptions have to be made concerning detailing policy into specific measures. Finally, also the mobility forecasts are based on certain assumptions, e.g. demographic and economic developments”.*

19 OTHER MATTERS IDENTIFIED

19.1 Behavioural issues relating to the deployment of (semi) autonomous vehicles

Whenever the topic of semi or autonomous vehicles was raised there seemed to be a heighten level of concern from road safety experts, few if any saw it becoming a reality in the short term such that it would immediately improve road safety outcomes and often the opposite view was expressed (i.e. it is many years away).

Many autonomous vehicle proponents believe that the machine has a better safety record than humans often quoting the recent Tesla performance as one fatality crash in 130,000 miles of driving, however, did Tesla update their figures as soon as the second fatality occurred very soon afterward? If anyone of these two crashes was to involve multiple fatalities, due to passengers being involved these results would not look quite different. Thus care is needed when we see headlines and quotations about relative safety performance of vehicles before we have substantive scientific evidence. A small sample is not necessarily a statistical sample nor does it represent an uncertain future.

Discussions with behavioural psychologists, however, identified retraining is necessary for drivers of semi-autonomous vehicles as for the next 20-30 years the driver will need to be both the driver and the supervisor of the automated processes. This requires additional skills which in the main have not been considered by practitioners and policymakers as the reaction time needed for a driver to change from being a supervisor to the driver has been shown to be problematic.

This has been demonstrated by behavioural psychologists in other industries, for example when people have to take over control of machinery, there is a significant lag time before the brain is fully engaged from a relaxed state. Hence this issue is emerging as a significant problem for vehicle manufacturers particularly as drivers behaviours will vary when faced with these additional challenges refer (Hagenzieker).

The first generation of semi-autonomous vehicles places increased, not less, mental load on drivers as they have to constantly monitor that the vehicle can see the signs and lines and is always staying between the lane lines. These new systems may have up to 7 ranges for “car following” distance and the closer you drive to the vehicles in front the more the driver has to concentrate to look out for mistakes. Is choosing one of these settings something that the driver should be choosing, as it may be a function of the driver skills or the “present” alertness level of the individual driver (they may be tired, distracted, eating or talking to others in the vehicles)? When a vehicle is travelling at the speed limit (i.e. 100km/h or 28m/s) it only has 1m either side to stay in the centre of the lane and thus it only takes a fraction of a second at this speed for a vehicle to wander out of a lane. Currently, the supervisory role of a driver has proven to be more tiring than physically driving the vehicle although short distance driving might be ok. This may defeat the purpose or benefit of having such vehicles.

How non-automated vehicles and other road users will interact with automated road users has emerged as a major problem for behavioural scientists. It is well known that in complex driving situations that drivers, riders, and pedestrians collaborate subconsciously to a very high degree, and this occurs very rapidly by means such as: making direct eye contact, a head nod, observing changes in the lane position of a vehicle, the change in gate of a pedestrian or noticing a small speed change in the other vehicle, and watching for warning signals (i.e. brake lights and indicator lights etc).

This collaborative behaviour generally creates a very safe road environment when other vehicles and pedestrians are coming into close proximity to your own vehicle (i.e. turning at intersections, lane changing or when crossing the road as a pedestrian) Pedestrians and particularly young children may expect an automated vehicle to see them and slow down or stop when they walk or even run across the road. What if the vehicle does not respond as expected or as humans would behave?

What are the current or proposed technical solutions to replace sophisticated split-second human collaboration behaviours which occurs in the blink of an eye, or a nod of the head? Discussions indicated that science had a long way to go before the current extreme level of expectation surrounding the Autonomous Vehicles becomes a reality for a significant percentage of vehicles.

As much of the driving on urban roads involves some form of collaborative driving behaviour and interaction between the various transport modes, the two physicists met during the Churchill Fellowship, who both worked in the vehicle industry, (i.e. Daimler Benz and VW), separately raised this issue and indicated that the vehicle technologies were a long way off picking up driver/rider cues or pedestrian or stray animal cues in very complex road environments and hence full automation of vehicles was still had a long way to go and their use would not be widespread for driving in complex situations for many years hence.

A clear message received during the Churchill Fellowship, particularly amongst Road safety professionals, was not to put all our collective energies into the hope that various levels of autonomous vehicles may one day provide enhanced safety when they eventually reach maturity and occur in significant proportions in the next 20-30 years. These vehicles may also only make a significant difference to road safety when they reach high levels of saturation, (i.e. 80-90% saturation). We therefore need to focus our effort and energies today into what is already known and what works and develop "star ratings" for crash avoidance technologies such as the safety applications and the handling performance of vehicles that enable vehicles to safely stop and steer under emergency braking conditions to avoid crashes.

The array of vehicle performance discussed in Section 10 (Are Vehicles Safe when Faced with an Emergency Stopping Situation?), is concerning when we currently have the means to test and rate vehicles on these more basic issues. Some vehicles on our road and some of the aftermarket equipment fitted is such that they should not be driven on our roads at highway speeds. It seems to many practitioners in discussions that the current narrative appears to be happy to speculate about an as yet unproven future rather than act on what is already known and available today. Thus talk of the autonomous vehicle was seen as a major distraction and concern to many of the road safety professionals met during the Churchill Fellowship. Hence the current hiatus this decade in the road toll may in some way be linked to when this alternative unknown future narrative began to emerge strongly some 7-8 years ago particularly since 2010. Many Road safety professionals mentioned that it was somewhat of a distraction of effort and resources to focusing of the current problems of today.

19.1.1 Optimisation of traffic flow will require traffic control for the foreseeable future

Discussions were held with experts regarding the expected efficiency of autonomous vehicles. Often proponents seemed to speculate that autonomous vehicle will provide a "get out of jail card" to solve our congestion problem with very little empirical evidence as much of this work is from models with little understanding of traffic theory or how road networks are designed, operate and how the transport tasks works. Most research literature on this topic suggests both higher speeds and smaller headways are required, however they often have not considered that basic road geometry would need to change to enable higher speeds (i.e. requires larger radius curves with more super-elevation) so vehicles can remain in contact with the pavement at higher speeds and the faster lane changes into smaller gaps will make it very uncomfortable for passengers (i.e. they would get car sick and the elderly will find it difficult). Such consideration is the basis for current road design practice and seems to have been largely ignored. It seems that many of the traffic modelers do not have a basic understanding of physics and road geometry. Some assumptions in modeling may result in an unsafe operating environment.

For example on a single urban motorway in Melbourne (M1) with up to 900,000 vehicles per day entering the system at all of it's on-ramps, which involves some 6 million lane changes each day, thus how will these vehicles be managed when autonomous vehicles arrive in significant numbers. It is most likely there is a need for an "autonomous traffic control network" to manage the millions of autonomous vehicles possibly by providing them each with a up to the minute plans (i.e. like "flight plans" for aeroplanes) that will also optimise all the other road users on the same road at the same time (i.e. 50,000 on the M1 motorway in peak hours). As drivers will still like the flexibility to be able to make travel choices when they already on their journey "flight plans" will be upgraded as they drive. Thus who is working on the problem of controlling millions of vehicles in real time, all with unique origins and destinations to optimise the road network?

Therefore understanding the complexity of the task and the human interactions and behaviours involved means we have a very long way to go before the autonomous vehicle delivers improve safety and improved efficiency on road network and specifically on the urban motorways where vehicle interactions occur at speed and much faster than current vehicle technology purports to be able to do (i.e. driver headways might average 1.5 seconds) but the shortest headways on urban motorways are typically 0.3 seconds when drivers are physically making lane changes which are well below the level of current technology. Any lane changes faster than current levels will make it uncomfortable for passengers particularly the elderly[220], as they will be jerked around with swooping type lane changes. With respect to a large number of issues raised throughout this report, Ii would appear the vehicle following models and lane changing models, and network optimisation, are not well developed and hence the fundamentals of transportation are not well understood for real-time operations, optimisation and safety.

Many autonomous vehicle researchers do not have the data on vehicle headways and lane changing associated with urban motorways and, hence have made many assumptions in their models that bear little resemblance to the reality observed on our road network. Often researchers state in their reports that lane changing is banned or travel is on dedicated lanes and, often such consideration is not taken into account at all. Dedicated lanes are unlikely to work in urban areas due to the complex trip patterns and high turnover of vehicles (e.g. short trips).

Markos Papageorgiou Technical University, Crete advised, that his recent work modeling Semi-Autonomous and Autonomous vehicles as part of European TrafMan21 Project, was that these vehicles will still need traffic management, This is necessary if the road network is to be operated both safety and efficiently to achieve at least the same current beneficial level of optimisation we experience today on our roads with best practice operation, where motorists are able to still to modify their journey, their destination or their route and their lane choice based on the context they experience while driving.

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[220] Note most road design standards is based on parameters to achieve human comfort levels – will passengers feel safe and comfortable travelling with greater forces acting on their bodies.

It has been well known for many years that the optimal travel route for an individual vehicle is not the optimal route for all road users as a whole. This is the knowledge that most motorists have already learned, as most drivers know what route choice or decisions work best for them and many instinctively adapt their journey as traffic conditions change. Road authorities have known for many decades that drivers adapt readily, hence this is why road networks adapt relatively quickly to most incidents events and also to longer-term road work events.

Thus to achieve a network optima, we must have a high degree of physical traffic control of all vehicles at far higher levels of sophistication than offered today. Currently most road users are not controlled or controllable, (i.e. as pedestrians will always need to cross busy roads) and other modes of transport will be increasingly in conflict with the motor vehicle, (i.e. trams, buses, motorcycles, cycles, e-bikes, pedestrians) and other lower energy and lower sophistication vehicles types which are currently emerging in Europe (i.e. powered scooters, powered skateboards and mobility vehicles for drivers with limited mobility).

19.1.2 Founded or unfounded optimism?

Rune Elvik suggested that cooperative or autonomous vehicles promotional information appeared to be based on unfounded optimism, (i.e. there will be some safety improvements) but the computer is a long way from being as good as the human eye and the human brain. This was a common view expressed by all researchers during meetings.

There appeared to be a common belief that Road Safety research and programs had stalled, as decision makers were distracted by the promise of a more futuristic paradigm, that may or may not come to fruition within the next 30 years, and hence in the meantime motorists were dying on the roads when there is a great deal that could be done to reduce the road toll further. Thus the rising road toll at present maybe in part be due to the distraction of transport leaders to an as yet unrealized future, and hopefully, we will see a correction soon and refocus effort back on to the current day problems.

It was also mentioned in the Netherlands that semi-autonomous vehicles do not recognise mobile crash attenuation vehicles on their motorways and, the vehicle designers blamed the manufacturers of the crash cushions for not meeting certain standards rather than blaming their own vehicle onboard technologies for not seeing the unexpected. What else will these vehicles not see such as small children, kangaroos, deer, camels, and horses, or when driving through snow, sleet, dust or flooded and washed away roads in the Australian outback?

It also seems likely, where these autonomous vehicles have been involved in serious crashes, the legal onus is on the driver for ignoring warnings to take over control. As discussed above, the behavioural scientists such as Professor Marjan Hagenzieker are warning that a driver who is not concentrating will be slow at taking control in complex situations. Hence we have a lot of behavioural science and legal work to do before we should be talking up this not yet proven technology. Just because we were able to send a man to the moon in the 1960s did not mean 50 years later it has become an everyday event or is cost effective and affordable to the masses. In fact, the very high potential risk of loss of life in the moon voyages was one of the reasons why this program was discontinued and humans have been replaced with robots and vehicles to reduce costs and risk to life.

At all meetings where this topic was discussed during the Churchill Fellowship, experts were highly skeptical of the autonomous vehicle which they believed was more than a generation away and currently being “not much more than novelty value” or a distraction. Many experts encountered on the Churchill Fellowship were outspoken and spoke of the lost opportunity, as high profile people and leaders promoted the 30 years ahead solution and are seemingly missing out on the current reality that new vehicles in the Netherlands and Sweden have a life expectancy of 20 years, and that there are many tangible vehicle safety initiatives that could be progressed much sooner or which are available today. For example, mandating 4 or 5-star ratings for all vehicles and mandating that all trucks and cars to have Electronic Emergency braking (EEB), blind spot warning/lane change assist, lane keeping, Ecall, Bcall, fatigue monitoring etc.

In summary, discussions indicated there are many exaggerations and misconceptions about semi and fully automated vehicles and in the short term drivers will need to be trained in supervisor skills of these complex systems. Evidence from behavioural science research shows humans may not act as quickly as required when moving from supervisory role to driving, unless they are kept highly alert and this will cause more driver stress and fatigue, causing the driver to fatigue earlier that may not have any benefits over the driver driving the entire journey. Research into the behaviour sciences for people in road transport and the interactions with other existing and emerging modes of transport, means these branches of the behavioural sciences are still in their infancy although much knowledge can be drawn from studies of human behaviours in other fields.

19.2 Decentralisation of road safety programs has proved problematic.

The RWS decentralised road safety programs to bring the road safety solutions to the local areas with local problems. Such an approach did not work particularly well as it was considered that complex technical problems cannot be solved by the diversity of strategies based on simple opinions and local views of essentially untrained committees. Also, each local area had too few crashes of the same types to develop any long-term collective knowledge base or understanding of the crash types. **It was noted that you do not do brain surgery by consensus of local opinion in the community and you do not solve airplane crashes by opinions of the community where the plane crashed**. Such should also be the case with road safety which requires professional insight from multiple disciplines.

Therefore road safety must be kept as a specialist area of multi-disciplines of science including engineering and behavioural sciences. Hence solutions must follow a rational path starting with naming the problem, understanding all the mechanisms involved in the problem, and using suitable evaluation methods to test the hypothesis and solutions based on the problem and the mechanisms involved. This must occur with thorough research and application of appropriate analytical methods and treatments using scientific and well-tested methodologies.

The road toll has plateaued generally across the western world against the downward trend of past decades and as quoted honestly by Peter Van Viet Sustainable Safety in the Netherlands ***"Good explanations for the increase serious crashes and fatalities are still missing"***.

The above comment summed up much of the sentiment across my European meetings and hence one of the reasons I embarked on the Churchill Fellowship was to break open the long pause in our collective thinking that seems to have missed the changing circumstances of crashes which to a large extent have gone unnoticed. Hence road safety is somewhat stuck in a bit of a historical rut with practitioners trying new ideas often without solid evidence, and with researchers concerned that it is likely that the "decade of action" will not make any gains if current trends and approaches continue.

19.3 National benchmark for emergency services

Discussions also highlighted that the Netherlands had a national benchmark for emergency services to attend a crash is 20mins. This is most likely quite achievable in a small country of 45,000 square kilometres. However, does Australia have such a performance target and if not we should be investigating this important matter given that we have a growing rural road crash problem?

19.4 Do we know what to do next?

The mood of most meetings in Europe would suggest that road safety specialists were at best surmising the cause of recent increased casualty crashes and hence suggesting without much exuberance or confidence the usual stereotype problems as these appear believable and rational to the public, but are not necessarily being supported by tangible empirical evidence. Hence possible explanations expressed with little evidence are the typical ones people in the street and media talked about. Issues such as:

- more distraction by smartphone use,
- speeding,
- alcohol,
- mobility increases - up by 2 percent per year, and
- the need for more police enforcement.

However, the good news is that researchers were beginning to recognise that their current strategies and programs are not working as well as anticipated and, hence new evidence-based approaches are needed. The current Netherland's road safety plan runs to 2020, however, the following concluding statements from Peter Van Viet are important:

1. *"there is a need* ***for a new approach*** *which motivates politicians;*
2. *it is clear that the quality of the current accident registration (police records) is insufficient;*
3. *the new approach focuses on high-risk sites and be proactive instead of reactive;*
4. *they are developing a risk-based approach with safety performance indicators similar to Sweden."*

19.4.1 Safety through changing mode to non-road-based transport

The following discussion was an interesting aside on road safety which was highlighted several times during the Churchill Fellowship. It was indicated that although Australian may like their public transport system, trains, trams and buses, however, they were described quite frankly in one meeting as "really being a museum piece" (i.e. from the 1930's), compared to modern mass transport systems available in Europe and Asia. The general thrust of the discussion was the Australian public requires high speed interconnected mass transport across their urban cities (i.e. not just radial transit), to get people around the cities without further congesting the centre of the city and without interacting with road transport. This will provide a 21st-century solution to the road safety problem as rail is much safer than road transport.

Following this line of discussion, Australian capital cities needed to start building or expanding their underground Metros. Potentially using road pricing with appropriate public transport pricing (i.e. higher pricing to assist cost recovery) and only subsidise fares where needed, to fund the investments required to provide and maintain Australia's liveability standards for the existing populations and for the 10's of 1000's of new residents arriving in our capital cities each year.

Thus moving more people to safer modes such as mass transport for suitable trips was highlighted as a major way to bring the road toll down, and hence why Australia will find it difficult to compete in road safety with many European countries that have better road safety outcomes than Australia. These cities and countries which have already invested in safer systems for moving people and thus their context for road safety are vastly different to Australia (i.e. the Netherlands has a major bicycle fatality problem) rather than the rural road or local road crash problem we have in Australia. Building a mass transport system requires long-term vision rather than a simple short term project/business case approach as such systems are transformative for land use and transport. When we sit back and understand the bigger picture regarding our future transport needs and how the transport will look with larger populations, mass transport quickly becomes a logical imperative, that current transport modeling and transport forecasts cannot foresee, as models use incomplete metrics and imprecise methods based on constrained thinking. A visionary idea such as the introduction of the Internet cannot be judged on today’s thinking.

19.4.2 The Netherland’s changing road safety context

The following is an example of context and why new data sources are required to understand and address crashes from different contexts. The Australian crash context in 2017 is not the same as in the 1970’s however much of our raw data for analysis is coming from the similar sources that were primarily developed 30-40 years ago (i.e. police records).

The Netherlands for many years have adopted their own “Sustainable Road Safety Program”. Discussions with RWS in Utrecht revealed that 50% of travel in the Netherlands is on motorways and FSI crash numbers were rising. However the 61% of crash problem in the Netherlands was not on motorways or with moving motor vehicles, but rather with pedestrians, cyclists, mopeds, motorcycles and disabled vehicles, hence the context for road safety is quite different to Australia and maybe Australia needs to be better understanding context.

In 2015 there was an increase in number of fatalities of 30% (63 to 82) on the national roads and on all roads in the Netherlands of 9% (570 to 621) refer (Figure 83 for breakdown of fatalities crashes in the Netherlands). Hence trying to transfer road safety programs between countries has its limits unless we look at the problem through similar metrics and focus on our own unique problems.

The entire country of the Netherlands is only a little over 4 times the metropolitan area of Sydeny or Melbourne and all their major cities are connected by relatively high standard motorways and railways. They have a modern mass transit system on a scale that does not exist in Australia and almost 40% of all trips are made on the bicycles. Hence it is not a surprising that they are much better overall road safety statistics per capita compared to Australia. Hence why has Australia focused heavily on Sweden’s and the Netherlands’ approached to road safety when their context for road safety is vastly different?

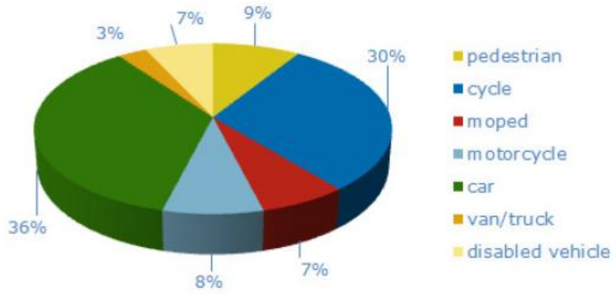

Figure 83 The breakdown of fatality crashes in the Netherlands (2015)

19.4.2.1 The Netherlands has a changing context - increased elderly driving and cycling

In the Netherlands the elderly (i.e. those over 60 years old), have a growing problem because they are becoming increasing responsible for minding grandchildren which often requires peak hour travel by car or bicycle to visit the family. Also adults in the Netherlands are having to look after elderly parents and are caring for them more. This involves additional travel outside of work hours when people are more fatigued or stressed. The elderly also now travel a lot more than they used to, as their lifestyle and affluence mean they like to travel to distant places to visit friends, parks and for recreation. As 50% of travel is in the Netherlands is on motorways this increases the travel on motorway during in peak periods which is the time when many FSI crashes are occurring, a similar phenomena to what is occurring in Australia although Australia's overall travel on urban motorways over the day is much higher than in the Netherlands.

An emerging problem in the Netherlands is elderly cyclists as some 40% of trips are cycling and cyclists over 60 years old are involved in 46% of crashes with serious injuries which do not include hitting other vehicles, but objects (i.e. the ground or fixed objects such as trees, poles, and walls). The elderly are buying E-bikes and the extra speed, power and changed the centre of gravity means they can fall off easily and crash, and this is combined with extremely low levels of helmet wearing in the Netherlands. Elderly cyclists and pedestrians over 60 years old are more fragile and get injured and tend to break bones etc. Then they are more likely to die in hospital from downstream complications additional to the injury that caused by initial crash (i.e. an infection).

Some 52% of serious injuries are on the bicycle and occur without motor vehicle involvement, (refer Figure 84 for the breakdown of serious injuries in the Netherlands). It is clear from visiting many European countries that the road safety context is very different and the safety problems there are not the same as our Australian problems. Thus Australia can understand the road safety principles but should not be blindly copying their road safety programs as seems to have often been the case since Australia changed its metrics for measuring crashes some 10-15 years ago from crashes per 100M VkT, to the number of hospital admissions per 100,000 population. This shifted the focus of Australian road safety to comparing and following other countries who were suddenly apparently better placed[221] than Australia, rather than understanding the actual crash problems in our own unique context. Whilst the change in focus shifted the problem to a public health issue, which guaranteed continuation of road safety funding, it also appears to have set us back many years as we no longer seem to understand to the same extent our own unique Australian road safety context and hence we have moved to other countries solutions and continued to match treatments to simple patterns rather than finding solutions to known causes as we did so well in the past.

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[221] Many countries with better road safety outcomes than Australia have much greater travel by modern mass transport systems which are still being built and much less reliance of the motor vehicle. If people travel less by the motor vehicles it is likely they will be safer per 100,000 population an issue which seems to have been overlooked by road safety analysts in Australia. If Sweden for example, has less vehicles per capita than Australia for example 0.9 x Australia, which then travel less distance per annum (i.e. 0.8 x Australia) it may be that their safer road outcomes are directly related to this metric (i.e. 0.9x0.8 = 0.72 x Australia road toll) which is therefore makes Australia about equivalent with the comparison countries having much more travel by much safer higher speed mass transit.

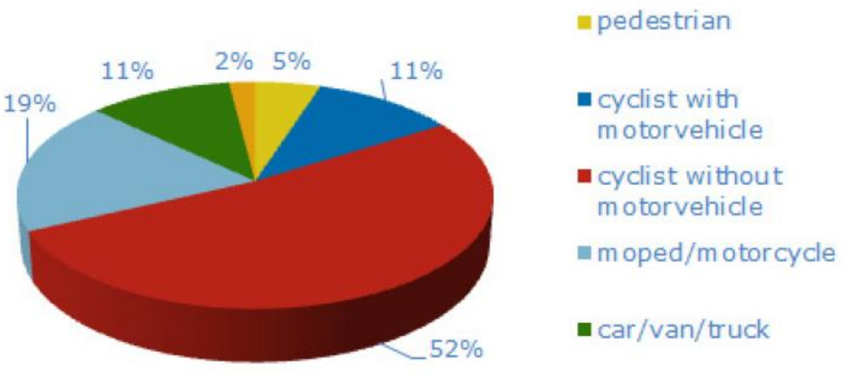

Figure 84 Breakdown of serious injury crashes in the Netherlands (2015)

Also in the Netherlands, the behavioural scientists have identified the emerging behavioural issue that the rise in older drivers giving up their vehicles and then moving to other modes of transport is revealing itself in the crash data as a major problem. For example, when older drivers lose their license they may revert to cycling or the mobility scooter, where the crash statistics are now showing this category is rising fast. Statistics are showing it may have been safer for older drivers to have kept driving their vehicles. Understanding these behavioural issues will not come without further research.

19.5 How do we decide whether a crash cluster is a systematic problem

For many years elements within the road safety industry have argued rather strongly at times against proven scientific and statistical methods that when studies of crashes are undertaken that there is no need to undertake regression analysis to remove the effects of randomness from the findings accident studies. The rising road toll may be a case of "birds coming home to roost" as we may now be treating many locations with historically low numbers of crashes, and where randomness exist these crash studies will almost always have good after study findings as outliers (i.e. anomalies with higher crash numbers) usually return to the mean in the next period whether they are treated or not. Refer to the AustRoads report SAG2090 quoting crashes in Auckland, New Zealand **wherein 2013, 79% of the fatalities and serious crashes occurred at sites with no fatal and serious crashes in the past five years, and 64% of crashes occurred at sites with fewer than two injury crashes in the same 5 year period** and, thus crashes are extremely rare event from billions of events of exposure.

Every year in Australia the almost 18.9 million registered vehicles, travel more than 250 billion kilometres on 900,000 km of the road network resulting in 40,000 casualty crashes and 1300 fatalities. On average one casualty crash occurs every 6,250,000 km travelled, a distance of 16 times to the moon, and one fatality crash occurs every 192,000,000 km a distance much greater than travelling to the Sun. The perceived risk of a fatality therefore to motorists is very small, (i.e. 1 in 192,000,000km travelled or mathematically a 0.0000000052 chance of occurring[222]). Thus these events are very rare events indeed, where we do not know with any real certainty where the next

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[222] This compares to winning first Division in Tattslotto) =0.00000011 which is orders of magnitude more likely than a crash (i.e. 0.0000000052)

event will occur or what the consequences will be. The motorist, the general public, and researchers are not good at comprehending and communicating events which are substantially random. ***“Humans generally aren’t great at reasoning objectively about uncertainty or random events as we go about our daily lives”*** (Today)***,*** *Refer* Appendix C*, Section1.6, (*The problem of narration bias*).*

Thus more work is needed to determine what the crash distributions and patterns would be expected if all crashes in Australia were considered either fully random versus fully systematic. This will reveal how we should determine which crash clusters are systematic or random (i.e. how does randomness look different to systematic?). For example, Figure 85 and Figure 86 below show different maps of crashes in Victoria, which due to narration bias described in Appendix C, Section 1.6, humans see patterns and communicate concepts through simple concepts and stories. Mathematicians when looking at this data may see many different features such crashes not being random with respect to traffic or exposure (i.e. you can see the major highways and populated areas is these maps), however away from these populated areas or busy routes crashes may appear to be random spatially in most parts of Victoria. Thus if crashes are substantially random you would expect most locations to have no crashes, fewer locations to have 1, less again would have 2 and less would have 3 crash in 5 years etc. and a very few will have a high number i.e. 6 or more as this is the pattern randomness yields. If the crashes follow a distribution such as Poisson distribution you would see a few sites with a high number of crashes. Then the question must arise as to whether a location with 5 or 6 crashes of unrelated crash types is any more dangerous than another site with 2 or 3 of the same type?

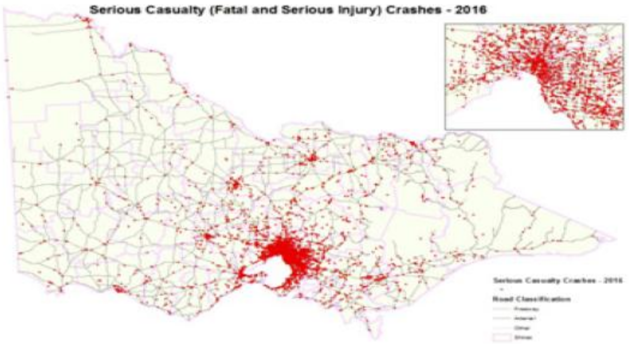

Figure 85 Distribution of fatal and serious injury crashes in Victoria - random or systematic?

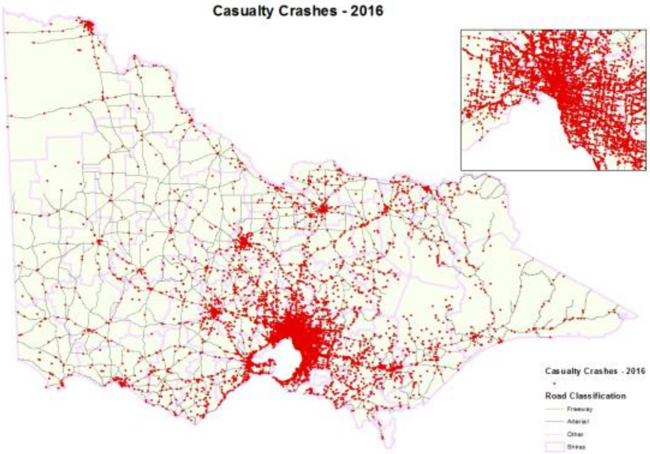

Figure 86 Distribution of casualty crashes in Victoria are they random or systematic?

Understanding the mathematics and science of statistical methods used by most other industries may result in a shift in our approach to road safety, except for sites with very high numbers of similar crashes as was the case 20-30 years ago. Over a long period, we have substantially fixed most of the really bad crash locations, although some sites will always exist and need fixing, this may no longer be the substantive road safety problem it once was.

Route treatment (e.g. installing safety barriers) are still very useful treatments, however as with urban motorway FSI crashes, vehicles are crashing into other vehicles travelling the same direction, and are not generally running off the road and hence we may get better return on our investment when we focus on tools targeting crash avoidance by providing drivers with another set of hands and eyes (i.e. safety that travels with the vehicle wherever it goes) as we cannot guarantee where the next crash will occur or what its consequence will be. Many of these tools currently exist hence road safety strategies may need to consider mandating or promotional activities to increase their usage.

19.6 Sweden and Norway lead the way on vehicle safety standards

In Sweden, the Auto brake is compulsory as well as 4-star vehicles minimum standard. In Norway, road safety policy is along similar lines to Sweden promoting for 4+star vehicles only. Should Australia continue to allow new cars with low star ratings to be purchased or ban them as Sweden has done? Any new car built today Sweden expects it to be still registered in 20 years time hence the longer we wait to improve vehicles standards the longer the legacy continues. Thus the changeover of the fleet will always be slow and hence every year lost before we act is a lingering problem for future generations of Australians. Fatigue may also be a bigger problem in Australia than we currently realise due to the long distances travel on rural roads (i.e. unique to Australia and Canada etc.) , thus this is another area Australia could act early as these types of applications are relatively low cost to provide.

19.7 New road tunnel standards are required

The concept of “Clean” road tunnels on motorways was discussed with tunnels providing limited information to drivers in a tunnel under normal driving conditions and no information outside tunnel portal for 200m. This means that speed limits and messages are not displayed so the driver can concentrate fully on the road. When there is an incident or traffic problem, this is the only time speed signs and VMS signs are lit up. Driving through many European tunnels that had adopted this feature as well as driving in a tunnel on a test simulator, provided a sense that it seemed to be a much safer and easier to drive in a “clean” road tunnel as it reduces the workload on motorists. Similar practices occurred on the surface roads in Europe that are also worthy of further investigation.

19.8 Is the current enforcement regime effective and fair?

Discussions revealed that Australian traffic fines seem to be expensive compared to many other countries, and countries with apparently better road safety outcomes, suggesting this carrot and stick mechanism to bring about road safety change needs to be independently investigated.

At times fines may be considered to be low or very high as its impacts will depend on relative affluence and income levels hence its impact may be quite variable. Reports in the Australian media in August 2017 highlight this, as up to 50% of indigenous Australian's are in jails[223] in some parts of Australia for non-payment of traffic fines. This same group often has virtually no access to public transport, no access to driver training and need to drive to have access to employment and services. Some of the drivers in jail were teaching themselves to drive on outback roads so they could get employment to improve their circumstances. Has independent research been carried out into unanticipated social issues of road safety policy and strategies?

It is possible from antidotal evidence that traffic infringements may not be evenly applied across our urban cities and rural areas and that some roads may have higher levels of infringement due to higher levels of enforcement in some areas compared to others and hence higher numbers of fines issued, and higher numbers of loss of license in some municipalities. Hence the distribution of fines and both the socioeconomic impacts and measured safety improvements need to be independently investigated and inform road safety policy on the overall society benefits.

19.8.1 Crashes on motorways at night

In discussions it was indicated that there may be evidence that motorway crashes caused by "Nucleation Events" might be significantly lower in darkness under the same traffic conditions as vehicles brake lights are less obscured by vehicles braking up to 10 vehicles ahead in the traffic flow. In darkness, the brake lights can be easily seen by the driver as they reflect off the road and other roadside surfaces, giving the driver increased awareness and alerts them providing extra few seconds of reaction time needed to avoid a collision.

Other antidotal evidence following discussions, suggested that drivers may naturally increase their headway in darkness by a few extra metres which provide them with increased stopping time and braking distance. This extra reaction time might be enough to avoid some of the crashes or reduce its consequences to a "property damage only" or "minor injury" crash. Thus more research work is required on travel in darkness as the answers to these questions will already be contained in the crash records and traffic data sets and will be revealed if the seasonal variation of crashes using temporal traffic data (i.e. carrying out analysis of variations in daylight hours over the year).

19.9 Increasing problem of obscuration motorways

There seems to be an increasing obscuration problem as there is an increased number of larger vehicles (e.g. trucks and 4WD vehicles) using our roads as well as an increased number of smaller vehicles. This is a problem is expected to increase further in the future with the emergence of smaller electric vehicles. Therefore there is likely to be increased obscuration of traffic conditions downstream when a smaller vehicle is following a large vehicle which will further decrease driver's ability to observe potentially dangerous traffic situations ahead of them in the traffic stream and hence a higher crash risk could be expected.

19.10 Increasing blind spots on motorways

Other changes have occurred in our vehicle fleet such as an increased Safety Rating e.g. NCAP 5 star rating of modern vehicles has resulted in wider and thicker roof pillars increasing vehicle blind-spots. Hence "blind spot" warning systems may need to be considered as being an essential application for vehicles driving on our roads to overcome the adverse effects of vehicle design changes that have occurred to achieve higher crash ratings.

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[223] http://www.abc.net.au/news/2017-09-29/indigenous-woman-jailed-over-unpaid-fines-after-police-call/9002656

APPENDIX A

1 THE SAFE SYSTEM APPROACH ADAPTED BY AUSTRALIAN ROAD AUTHORITIES

The "Safe System" approach which Australia has adapted from Sweden's, i.e. Vision Zero Program and the Netherland's i.e. Sustainable Safety Program which seeks to consider human factors associated with crashes on our road system, by recognising that we all make mistakes and that our bodies can withstand only limited force(s). The Safe System approach considers how roads and roadsides can be made more forgiving of human error, looks at how our vehicles can save lives and reduce harm and ensures that the speeds we travel at are appropriate for the roads we drive on and for the other people who use them. Such an approach is not only about reducing the incidence of crashes, but also about reducing their severity when they do occur with particular aims at reducing the risk of potentially fatal an serious injury crashes.

The Safe System approach involves:

- designing, constructing and maintaining a road system (roads, vehicles and operating conditions) so that forces on the human body generated in crashes do not result in fatality or serious injury
- improving roads and roadsides to reduce the risk of crashes and minimise harm (by, for example, dividing the traffic, designing forgiving roadsides and providing clear driver guidance)
- Setting speeds that take into account vulnerable road users and the variability of risks on different parts of the road system.

The Safe System approach has four elements that underpin the principles of creating a forgiving road system: **safe roads, safe vehicles, safer speeds; and safer road users**.

The success of a safe system requires a shared responsibility between road authorities, road designers, road users and vehicle manufacturers where the road infrastructure is designed to eliminate or minimise both the likelihood and severity of potential crashes. See Figure 87 Graphical representation of the "Safe System Approach

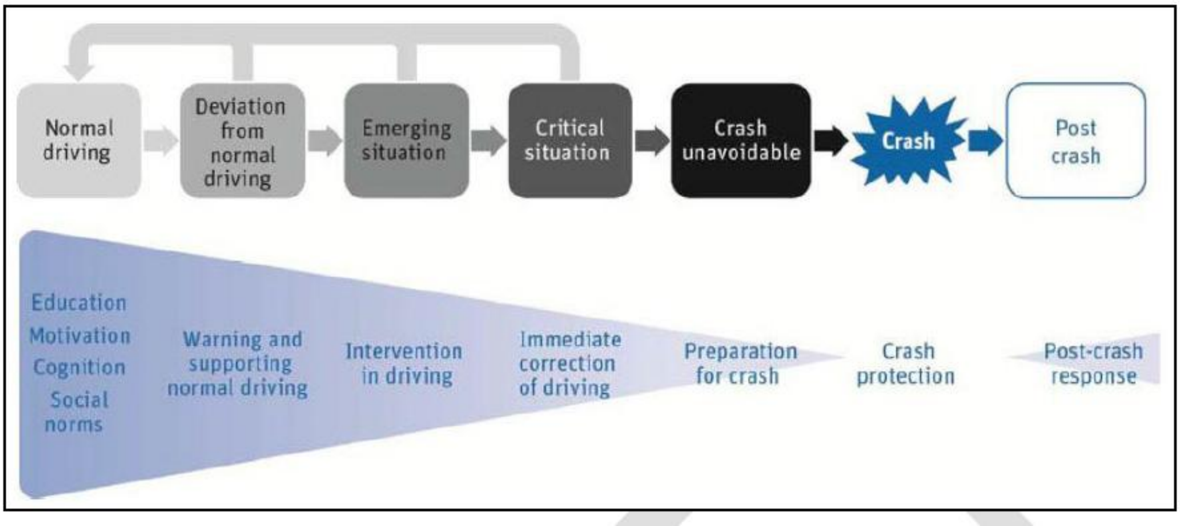

Figure 87 Graphical representation of the "Safe System Approach"

APPENDIX B

2 AN ALTERNATIVE PERSPECTIVE ON THE ROAD SAFETY NARRATIVE

There are many alternative voices from other parallel-industries who are also key actors in the road safety area over the past 30 year period when the road toll fell sharply and from these alternative perspectives alternative insights emerge that may assist in shaping future Road Safety Strategies. For example:

- **The medical profession** has delivered significantly improved emergency medical outcomes refer (Robert B. Noland, 2002) and improved practices (using new technologies CT scans and improved processes such as Triage) which have saved many lives and reduced serious injury outcomes;
- **The vehicle industry** has delivered much safer and more reliable vehicles including improved vehicle braking and handling and improved windscreen visibility in inclement weather with better head lights, windscreen wipers, air conditioning (clears misted windows);
- **Road agencies** have delivered sealed shoulders, widened pavements, improved reflective pavement markings (i.e. improved delineation of road, and improved road maintenance programs; and
- **The information technology and telecommunications industry** have delivered much faster response times for emergency services to attend crashes[224], with ubiquitous mobile phone coverage. This industry has also provided improved mapping, travel and weather information to drivers.

Hence it is likely that these additional factors might also have been equal or even greater contributors to road safety than road safety programs alone.

3 ADVANCEMENT IN-VEHICLE TECHNOLOGIES

On visiting the Mercedes Benz Museum in Stuttgart, Germany “history of motorised transport” as part of the Churchill Fellowship it was noted that they had a large display dedicated to the role of the medical and the vehicle industry in bringing down the number of FSI crashes. The museum openly highlighting the failure of Road Safety policy and other safety initiatives and hence why the vehicle industry needed to step in, see quotation Figure 88. from the Mercedes Benz, Museum in Stuttgart, Germany.

Mercedes Benz claimed safety through improved vehicle design and improved emergency medical treatment has saved more lives than improvements in road infrastructure and road safety programs. This is the alternate story that we often do not hear so clearly and nor is it openly promoted, within Australian road authorities and from road safety institutions. Road Safety programs acknowledge some of these benefits but primary only in relation to their own actions (i.e. the legislation of seat belts and Electronic Stability Control), which were primarily all developed and designed by the vehicle industry in the first instance. Even the excellent Australian New Car Assessment Program (ANCAP) which crash tests Australian vehicles has often tended to follow vehicle industry developments rather than set the absolute standards and or mandate for example, that Australia

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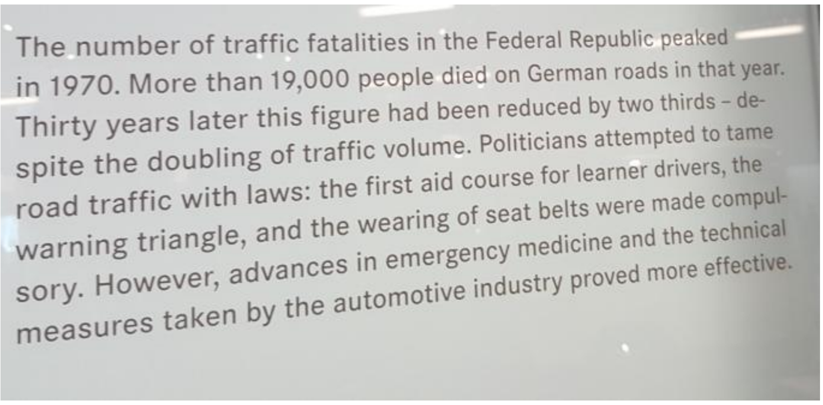
[224] It was noted that a 20 minute maximum emergency services response standard applies in Netherlands

should no longer be selling vehicles to consumers with less than 4 stars as is the case in some European countries with a better safety record than Australia.



The number of traffic fatalities in the Federal Republic peaked in 1970. More than 19,000 people died on German roads in that year. Thirty years later this figure had been reduced by two thirds – despite the doubling of traffic volume. Politicians attempted to tame road traffic with laws: the first aid course for learner drivers, the warning triangle, and the wearing of seat belts were made compulsory. However, advances in emergency medicine and the technical measures taken by the automotive industry proved more effective.

Figure 88 Different perspectives on road safety - Mercedes Benz Museum Stuttgart, Germany

Legislating for seat belts and ESC are only the tip of the iceberg when we look at a large number of safety features included in modern motor vehicles developed over the past 30 years, that have now become standard features and which have made major differences to reducing crashes outcomes wherever the vehicle travels.[225] For example:

1. Improved engines which run smoothly and no longer running rough or cut out when cold;
2. Improved braking systems (i.e. independent and power-assisted braking systems), disc brakes, wider wheels and improved tyre technology and fewer punctures than 30 years ago;
3. Improved steering, suspension, and vehicle handling systems;
4. Improved headlights and tail light brightness (i.e. improved visibility of road and for other vehicles);
5. Air-conditioning and demisters to keep windscreens clear and dry in inclement weather;
6. Steering columns that collapse during accidents or now substantially removed altogether;
7. Improved seat belts, airbags, and soft protection around the cabin;
8. Increased crashworthiness, crash cage, rollover, side impact protection etc.

It is fair to say, that whilst some aspects of improvement in medical and vehicles technologies have been acknowledged by road safety programs, however not to the extent that the benefits actually accrued and hence this poor attribution is likely to have lead to poorly focused road safety strategies and programs where these para-industries need to be at the centre of road safety decision making and strategy.

Hence depending on what reports are read or who we listen to, our perspectives and opinions on these matters will vary greatly and thus it is possible to arrive at completely rational conclusions based on incomplete assessment of the cause of crashes and what are the most appropriate solution or which areas to target in future road safety programs. However working closer with the medical profession, emergency services, ITC and the vehicle industry, needs to be at the centre of future road safety strategies.

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[225] Future road safety strategies will be most effective when safety travels with the vehicle to avoid crashes and which reduce impacts when crashes occur

APPENDIX C

1 NINE AREAS OF CONCERN FOR ROAD SAFETY SCIENCE

1.1 The problem of attribution

The subject of attribution, which is studied by psychologists as a theory *"supposes that people attempt to understand the behaviour of others by attributing feelings, beliefs, and intentions to them".* Humans by their very nature can attribute causes to problems very easily and if the attribution seems to be plausible it often becomes widely accepted.

In road safety for example, it has been easy to show the relationship of speed and crashes from physics that the faster you travel the more forces and momentum and thus the harder you will crash and the outcome should be worse. It is easy for us to believe that "speed kills". Also for many years "differential speed" was strongly prescribed as a significant cause of crashes, however this is no longer seems to be the case but rather "mean speed" seems to have a stronger association with crashes causation[226].

Both these issues - absolute speed and differential speed – are still quite difficult to prove empirically from data from various speed zones. For example some German and Dutch research is suggesting that impact speed, the speed at the instant of crash does not vary so much in the higher highway speed limits zones compared to much lower speed limits zones as science or logic might suggest (i.e. the majority of road crash have impact speeds less than 55km/h). This is why the NCAP vehicle crash test speeds are relatively low as this represents the impacts speeds of the vast majority of road crashes. Since we regularly see the worst crashes on TV we often get the impression all crashes are similar, which is far from the case as shown in Table 8 Energy Equivalent Speed (EES) from a sample of crashes 1791 where impact speed could be determined

The issue of speed is much more complex and requires further understanding. In several European countries visited during the Churchill Fellowship where speed has been raised to 130km/h, impact speeds have appeared to remain relatively constant (refer Figure 89 identifying typical vehicle damage zones).[227] These results may be not what researchers expected.

km/h	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	>100	Total
No.	629	579	342	151	57	15	9	7	2	1791
%	35%	32%	19%	8%	3%	1%	0.5%	0.4%	0.1%	100%
Cumulative %	35%	67%	87%	95%	98%	99%	99%	100%	100%	

Table 8 Energy Equivalent Speed (EES) from a sample of crashes 1791 where impact speed could be determined

Hence the issue of speed is a much more complex issue and requires further understanding. As in several European countries visited during the Churchill Fellowship the speed limit had been raised

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[226] In the case of urban motorway crashes such a finding is argued against in Section 14 Motorways Speed Management for Efficient and Safe Operations, for temporal "Events of Exposure" at times of high crash risk rather than when macro measurements averaging over the day or the year etc,

[227] *Just a thought from* Figure 31 *as it is quite noticeable that the safest part of a vehicle is in the centre of the vehicle (white zone = 0% deformation) something learnt by formula racing cars more half a century ago. Since many fatalities involve single occupants in "run off the road" crashes on rural, maybe there is potential with modern electrical steering systems and controls to make vehicles more versatile in relation to where the driver actually sits when driving alone as an additional 100-200mm offset might be life saving. Modern car seating has presets for forward and backward movements depending on the driver size and maybe they need presets for sideways movement to increase driver protection.*

from 110km/h to 130km/h[228], however, impact speeds have appeared to remain relatively constant. These crashes are investigated from both vehicle computers readings of the speedometer at the time of the crash and, by the extent of body damage sustained by the vehicles using modeling software which measures the actual deformation of the vehicle panels and sub-frame to determine impact speed, refer Figure 89 (identifying typical vehicle damage zones).[229]

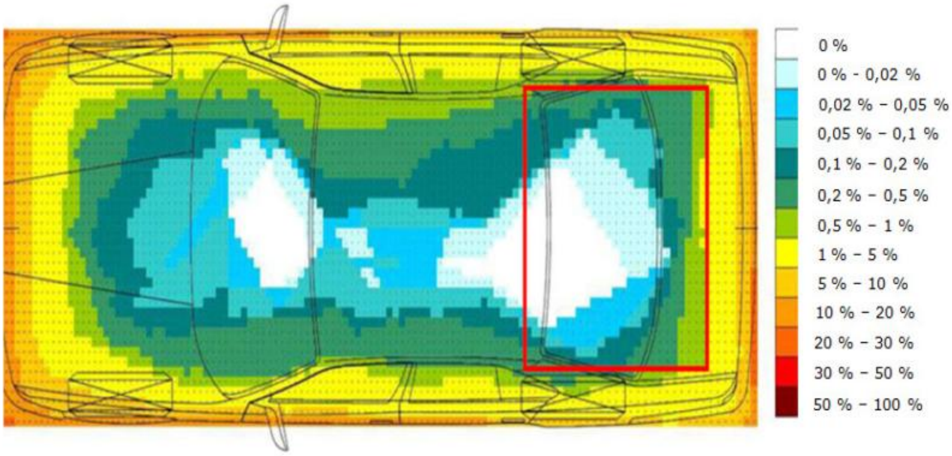

Figure 89 Identification of vehicle zones which are frequently damaged

Just because some measures in the before and after study have changed favourably to being either lower or higher does not automatically imply that the correct attribution of all the mechanism(s) involved in the change has been identified, or that the stated conclusions in the report have followed the necessary scientific methods and rigour.)

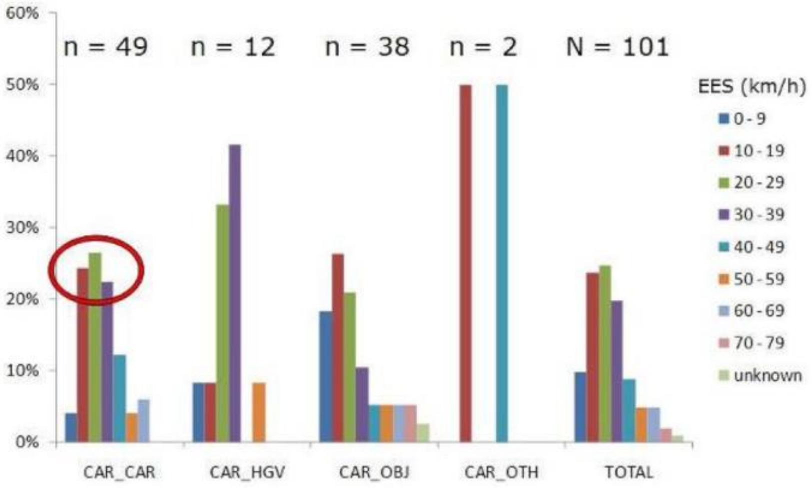

Figure 90 EES speed distribution of severely injured people (MAIS2+) for motorcar crashes

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[228] A common strategy in some European countries is to increase speed limits on higher quality roads (i.e. divided roads) to balance reduction in speed limits on higher risk roads. This is primarily about the community acceptance rather than much to do with road safety science.

[229] Just a thought from Figure 89 as it is quite noticeable that the safest part of a vehicle is in the centre of the vehicle (white zone = 0% deformation) something learnt by formula racing cars more half a century ago. Since many fatalities involve single occupants in "run off the road" crashes on rural, maybe there is potential with modern electrical steering systems and controls to make vehicles more versatile in relation to where the driver actually sits when driving alone as an additional 100-200mm offset might be life saving. Modern car seating has presets for forward and backward movements depending on the driver size and maybe they need presets for sideways movement to increase driver protection.

1.1.1 New forms of inquiry can reveal the true cause of crash

Analysis of hospital records and interviewing drivers and passengers involved in crashes, as per recent German studies by Claus Pastor, BASt German **I**n-**D**epth **A**ccident **S**tudy (GIDAS), refer (Figure 91 German In-Depth Accident Study (GIDAS)) and, Dr. Rainer Wiebusch-Wothge, Ruhr University study of children's involvement in crashes. This in-depth analysis reveals quite different perspectives and conclusions on the crash causes compared to the analysis contained within police records alone, which are Australia's primary data source for studying crash causation and identifying initiatives.

Figure 91 German In-Depth Accident Study (GIDAS)

In Australia when a serious crash occurs it is generally the police's job to interpret the road rules in relation to the law as to who caused the crash. Conclusions are often based on the traffic rules and laws that often do not fit the actual circumstances. This is the case with many urban motorway crashes where the trigger for a crash is not related to the actual vehicles or drivers involved in the crash.

For example, in the case of many motorcycle crashes on urban motorways, the motorists would most likely not see a motorcycle driving in their blind spots, and the fact that motorcycles have widely differential speeds compared to many other vehicles as they lane split, refer Figure 25 Vehicles event data displaying vehicles as particles revealing the lateral position in lanes. Raw data suggests lane splitting between the two fastest motorway lanes at higher speeds. It has been often stated that other vehicles cause 70% of motorcycle crashes and, this is correct in term of how the law is written and interpreted, which would conclude for example, that a vehicle side swiped a motorcycle.

However, relying on crash reports alone is no longer considered the best the way to understand the actual cause and solve the problem and to do research. Interpretations of crash reports have not be able to resolved long standing problems, even with motorcycle focused campaigns such as "Look Left, Look Right, Look Bike". An alternative solution might be equipping vehicles with blind spot warning devices and educating motorcyclists about the dangers of differential speeds where they are constantly moving in and out of nearby motorists either side of them blind spots (i.e. "they can't see what they can't see". On urban motorways it is clear from the data that motorcycles seem to like to create a 5th lane in a 4 lane motorway between the 3rd and 4th lane, refer Figure 25, and they often have a large differential speed compared to all the other vehicles.

Hence as discussed in Section 7.3, The devil is in the detail, as there are also many tens of thousands of necessary lane changes made on the motorway every hour, with some motorway sections having more than 2000 LC/h per kilometre of road. Combinations of "Blind Spots" and "Lane Shear"[230]the complexity is such that quite different education programs are required and quite different road safety solutions need to be developed in the case of motorcyclists.

In the Netherlands it was stated that when the cause of the crash seem to be obvious to the police, they did very little analysis (particularly in the case of single vehicle occupant "run of the road" casualty or fatality crashes). These are the crashes we must piece together the drivers' past few days of work, social activity and sleep, otherwise we may not correctly attribute the cause and develop appropriate responses to these increasingly common crash types.

More detailed analysis of crashed vehicles and post crash interviews provide an alternate assessment to either that of hospital or police records alone. A report based on a single data source might provide quite different assessment of the problem than when multiple data sources and lines of investigation are considered. The more that is known about a crash the more likely the cause of the crash can be correctly attributed. The better the attribution the better the road safety treatments will be.

The richer crash data collected (i.e. the BASt GIDAS program over some 18 years) makes current Australian crash records look a little inadequate for determination of attribution. The GIDAS study could determine whether the vehicle itself contributes to the cause, in the way forces were transmitted to the human body, or whether the subsequent medical intervention was influencing crash outcomes and survival rates. Dr. Rainer Wiebusch-Wothge, Ruhr University study of children's involvement in crashes found that interviews with children and visiting the crash site gave quite different perspectives from the official crash circumstance and cause contained in crash reports. Once circumstance and cause were understood new solutions were developed. My impression is it seems the current Australian road safety investments are primarily geared towards more infrastructure focused than understanding the primary causes. As discussed above then roads have higher flows the crashes type changes towards vehicle to vehicle rather than vehicle to infrastructure thus infrastructure solutions alone have limitations particularly as road progressively carry more traffic.

1.1.2 Other factors leading to poor attribution

Other factors leading to poor attribution stem from small inadequate sample sizes, poor use of mathematics and statistics and, the researcher coming to conclusions often based on logical opinions. Such studies are not necessarily scientifically based having investigated all the possible mechanisms at play in assessing the problem.

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[230] Refer section 18.2.1 Lane Shear

Attribution theory is emerging as a field of study and just because researchers can see a potential relationship does not mean it is correctly attributed to the cause and effect. For example somewhat irrationally it may be possible to show mathematically that casualty crash rates may have fallen inversely proportionally to global warming, or inversely related to the size of the hole in the ozone layer, or solely in relation to a particular DOT's road safety program. A different DOT in another country or State may have had similar reductions in casualty crashes with a different road safety program or even with little or no road safety program at all.

Hence understanding road safety is complex as there are many contributing factors to every individual crash and, as in the case with urban motorways many crashes are not necessarily related to geo-spatial elements as many crashes have a strong relationship with dynamic traffic loading; traffic density; lane occupancy and lane changing intensity which is now visible in the traffic data collected both in time and space.

1.1.3 Incomplete attribution is often evident in road safety analysis

Often conclusions about road safety interventions are made which describe the effectiveness of a particular road safety program or treatment, which apparently reduced crash numbers without any measurement or acknowledgment of the many of other known relevant factors that may have significantly changed the attribution in the analysis reports if they were investigated too. Examples are the impacts of:

- the vehicle fleet 5 years after the treatment is likely to be 5 years newer hence generally in the past 10 years they are a much safer vehicle fleet in the after study;
- road pavements may have been widened, shoulders sealed or pavements rehabilitated with improved delineation markings and road signage, and the impacts of maintenance programs at sometime during the assessment period;
- traffic volumes used to measure changes in traffic exposure (e.g. 5-year AADT) are not generally accurately measured and often coarsely estimated from sample data (i.e. 1 week of tube data) with estimated annual growth factors. This is clearly evident in traffic data collected for many rural roads;
- impacts of randomness and temporal traffic conditions at the time of the crash
- limited if any regression analysis to eliminate randomness in an initial sample of crashes – especially critical if the sample size is small (i.e. 5 or fewer crashes of a similar type in any five year period);
- little or no acknowledgment of systematic errors in the data which may be high in comparisons to the significance of the benefits reported (e.g. errors in traffic volume and speed data);
- improvement in technologies, telecommunications coverage and medical treatments which may have improved remarkably in the assessment period enabling faster communications and connections to improved medical intervention, reducing injury outcomes. This includes improved identification of crash location via GPS and mapping services to assist emergency services and improved training of emergency services operators (i.e. triple 000 officers);
- changes also to hospital practices including triage and also in getting patients home faster with increased home visits (e.g. Royal District Nurse Association) may also alter statistics related to

days spent in hospital following a serious crash and hence time spent in hospital time series may not be consistent;

- limited analysis which often only undertaken at the desktop without any physical visit to crash sites and, documentation, including a continuous photographic record and traffic volumes of both existing conditions, and during the evaluation period (i.e. 3-5 years) to identify other changes that may have occurred at the site, or nearby such as a parallel route being upgraded and taking away some of the traffic;

- inappropriate use of crash reduction factors which are have often been determined historically on the basis of incomplete statistical analysis and are not routinely updated[231] to reflect the changing context of crashes.[232]

A new Australian Standard or national guidelines for Road Safety Research methods and procedures may be needed that include: quality of data collected, methodologies, statistical methods, and independent[233] assessment of findings before analysis can be published or reported. Also Appendix B provides an alternative perspective on the road safety narrative highlighting many additional factors usually not taken into account or mentioned.

1.2 The problem of diagnosis

From many discussions in Europe a clear crash trend appeared to have emerged being an increasing number of serious crashes on motorways as well as on multilane divided highways. Preliminary analysis showed that crash numbers usually follow the daily traffic volume profile which has significantly increased in magnitude (i.e. more traffic) and changed shape (i.e. peak spreading) over the past ten to fifteen years.

Ten to fifteen years ago serious crashes in Australia tended to occur more frequently at night where typically crashes occurred during the 2 to 3 am period,[234] which were commonly depicted as being caused by high speeds, alcohol and fatigue etc. Thus speed alcohol and fatigue etc. became the focus of road safety programs. Serious crashes now occur throughout much of the daytime hours and the distribution of common crash times has changed significantly. Hence something(s) has changed that now require a different diagnosis as the mechanisms of crash causation and proportion of the crash types are clearly no longer the same as they were just 10-15 years ago.

The fact that the 2 to 3am period still has a high “crash rate” on urban motorways is purely just an interesting statistic as only a very small percentage of the total crashes occur at this time. Since the traffic volumes on motorways are very low during the 2 to 3am time period, it only takes a few crashes in 5 years to have a high “crash rate”. During the daytime hours however, the casualty crash numbers are 2-6 times higher for each of the daytime hours and the crash causation mechanisms and types of crashes are not in the same proportions as those at 2-3am. Hence reporting of crash rates has become less important statistic in understanding the true scale of the road safety problem and the causes. The changing nature of crashes means that crashes are more dispersed and hence many of these crashes are now in the “very hard to solve” category and as such their locations will have very low crash numbers.

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[231] Needs to be every 5 years or less

[232] Refer SAG2090 Best Practice in Road Safety Infrastructure Program Draft Report assessment in relation to monitoring and evaluation of Road Safety Programs

[233] Independently assessed by non road safety experts i.e. mathematicians, physicists and scientists

[234] refer Figure 6 USA Motorway in Colorado showing similar crash trends to Australia but also the USA still has the 2-3 am crash problem,

The urban motorway crash problem is changing as there is evidence that the dynamics of traffic[235] and their effects (i.e. shockwaves), which are upstream moving and, dense vehicle clusters which are downstream moving waves. Such effects are now seen in good quality traffic data, and are often the precursors of crashes. This finding is likely to be true for many other crashes on many other parts of the road network (i.e. crashes on local roads or divided highways or any higher speed road operating at LOS C or above).

1.3 The problem of investigation bias

Rune Elvik TOI has undertaken some excellent investigation on "Publication Bias", "Time Trend Bias" and "Zero Count Bias" in "meta-analysis". "Direct quotes from Rune's work are shown in "*italics*" below.

"There are many sources of bias in meta-analysis of which the following are the most important particularly to road safety investigations and the bias needs to be corrected for by analyst and researchers:

a) ***Publication bias****, which denotes a tendency* ***not to publish studies if findings are not statistically significant or contradict prior expectation or the vested interest of the sponsors*** *of the research*

b) ***Time trend bias*** *which refers to* ***a tendency for study findings to change over the time; if all findings are pooled independently when they were published, the trend will be passed over and the summary effect of the estimate will be misleading****.*

c) ***Zero count bias*** *which is* ***bias arising if studies with zero counts are omitted*** *or if inefficient continuity correction is applied to such studies"*

In Australia when researchers review publications that are written by others, there often seems to be a lack of acknowledgement of the potential for these sorts of bias to be present. Therefore, most readers of such research have not been adequately trained in being able to put the results in context of the bigger picture[236] and that the findings may be incomplete, as they have been omitted adverse findings,[237] and which may have been useful for referencing only at a point in time. Therefore often such findings are no longer totally true or representative of today's problems (i.e. "time trend bias").

For example, vehicle safety standards and technologies (e.g. introduction of Electronic Stability Control (ESC)) and crash ratings have continually improved vehicle performance in recent decades, road design standards and maintenance activities have also continued to improved and, driver education and training programs have changed behaviours. Hence the crash risk cannot be considered to be the same or linear over time; or the crash outcomes to be the same or even similar; or that specific road safety initiatives would continue to offer the same level of benefits (i.e. crash reduction factors); or would apply equally in another country, another context, or in a later decade.

Researchers who undertake literature review often do not seem to find or at least reference sources that have published results containing counter opinions to the topic they are writing on. Hence

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[235] High crash numbers occurs as soon as traffic densities reach Level of Service (LOS) C

[236] Researchers must always ask what is the missing from the data (i.e. the zero results and track down and report findings that is contradictory to their expectations or the view of sponsors). These types of findings are notable by their absence.

[237] This is an alarming trend where results that are adverse are not published and, sometimes this is openly stated by indicating more investigation is required (yet $m have been invested) and these matters should raise significant concern for the reader rather than moving on to the next sentence.

these **counter and neutral findings reports are usually conspicuous by their absence and this often appears to reflect the vested interests of the sponsors,**[238] and often many reports read as such. Also researchers who quote other studies findings should determine whether these other sources have produced findings that are scientifically prepared and which have statistically significant findings, using an appropriate analysis methodology, correct attribution of the behavioural and engineering effects, applied appropriate scientific rigour, have been independently reviewed and are not based on the authors beliefs or opinions.

1.4 The problem of copying without understanding context

Whilst the Churchill Fellowship focused heavily on motorway safety, the meetings also reveal many broader road safety issues that needed discussion and consideration. One such topic was the translation of road safety programs between countries and jurisdictions which can be thwart with difficulty, due to limited appreciation of differences in context. Following a program that was apparently successful elsewhere is not a scientific method.

1.4.1 Example of copying

In the field of motorway management and Intelligent Transport Systems (ITS) there has been many systems and treatments copied by other jurisdictions with little understanding or regard for context or, without checking whether it actually worked in the other jurisdiction(s) before they purchased the same or similar systems and, often without first checking whether they actually had the same problem(s), need(s) or circumstance(s). In transport there is often a strong copying culture, rather than a rigorous scientific methodological approach to problem assessment and tool selection.

For example, one road agency has a Traffic Management Centre with an Automatic Incident Detection System (AID) and over time many other road authorities have built Traffic Management Centres and installed AID system. However, very few AID systems on the open motorway actually work as this has been a known failing for over the past 30 years as stated by Prof M. Papageorgiou Technical University of Crete. Hence many Departments of Transport (DOT's) have purchased them yet very few of them actually work, as they have false alarms so much that operators stop using them and, hence they soon get completely switched off or the alarms totally ignored. This is an example of copycat solutions between various road agencies across many countries without any real measurable tangible benefits beyond the apparent need to have such a system because someone else has it. Copycat behaviour often becomes more prevalent when we run out of ideas or a perceived solution is needed quickly often to meet commitments.

Another example is that many modern European countries have lower numbers of FSI crashes than Australia on a per-capita basis. However these same countries also generally have modern high speed mass transit systems, which are used by a much higher percentage of the population, as well as higher bicycle use and walking etc. When mass transit systems are provided, travel by road is much lower per capita and, the roads are generally less congested. Other countries programs are therefore geared towards their context and do not necessarily translate to Australia with quite a different transport context refer Section 19.4.2,The Netherland's changing road safety context.

At one meeting in the Netherlands, it was stated strongly that

"Road Safety programs and solutions developed in Europe cannot be directly translated to

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[238] as described by Rune Elvik (Elvik, Publication bias and time-trend bias in meta-analysis of bicycle helmet efficacy, 2011)

***Australia as the transport context is quite different, however, any principles and learnings from the research in Europe may be able to be adapted and applied somewhere in the Australian context*".

Adopting European programs in Australia should only be considered:

- once the supporting research and principles have been fully understood by practitioners and experts;
- the differences in context understood;
- programs have been modified or solutions adapted and;
- the solution has been successfully trialed in Australia.

Hence the current road safety problem(s) must first be investigated and measured correctly before carefully controlled trials and appropriate analysis, controlling for randomness, systematic errors and bias. Trials must be proven to be sustainable and successful when tested in the field in Australia and not be based on a historical report written many years ago or in some other place. The nature of road safety statistics is that such a process usually requires a minimum of 5 years and thus road safety results cannot be fast-tracked.

We should not be copying overseas road safety programs until they have been proven in Australia with trials. For example, Norway, the Netherlands, and Germany have quite a different road safety contexts reflected by different levels of affluence, geographic position, weather conditions and mode share etc. for example: newer vehicle fleets; "snowed in" during long winters (i.e. Norway), mode shifts such as more bicycles and walking trips (i.e. the Netherlands) and heavy cross European travel demand resulting in higher levels of road freight (i.e. Germany). The Australian context is very different to Europe with less travel on mass transit systems in urban areas resulting in greater travel by road per capita, warmer climates (i.e. softer pavements with less friction), and higher a proportion of longer distances of travel in remote and isolated areas.

The European context for road safety is also very different from Australia with quite different travel patterns and demands in much smaller areas with much lower populations than in Australian capital cities. Vehicle age and vehicles types vary significantly (i.e. there are very few large 4WD vehicles in most European cities), which generally have high numbers of much smaller commercial and private vehicles, as well as larger numbers of motor scooters, electric vehicles and E-bikes. There are also large differences in mode splits between public transport, walking, cycling and general traffic. Seasonality plays a big role as tyres in Norway and Sweden for example, are changed for more than 6 months of the year to steel studded tyres for snow and ice and day light hours over the year can vary from two hours up to 22 hours each day.

For example discussions highlighted several situations where copying common think had led to increase crashes:

- a unique crash problem on the autobahn during a construction project where a combination of lane change ban and a merge situation resulted in truck speeds being reduced further from 60km from 40km/h which increased the crash rate up to six-fold. This treatment followed the ideology that slower speeds are safer however, it encouraged more cars to overtake trucks and increased the crash numbers. This treatment contradicted what the researchers who investigated the problem advised the project that the cause of problem was car/truck crash and, not a truck/car crash which meant that an entirely different solution was necessary and raising the speed of trucks would actually reduced the number of crashes (Prof. Dr.-Ing. Justin Geistefeldt, 2015),

- Discussion in Sweden indicated that the once popular and highly promoted two plus one lanes in Sweden may have actually increased crash risk at their terminus treatment, as vehicle merge at higher speeds and while still trying to get ahead by overtaking at the last minute. This is a well known problem on multilane motorway facilities in Australia with a lane drop and also in the UK. VicRoads has been progressively eliminating these types of treatment on urban motorways as part of it "Managed Motorway" program. Midblock lane drops on urban motorways when there is little or no chance of congestion (i.e. LOS A) may operate safely, however if the context changes and there is a chance of higher traffic volumes (i.e. traffic density greater than LOS B), they have been known to induce congestion and lower the overall capacity of the road and contribute to a higher crash risk. Discussions in Norway indicated that 2+1 lanes had a sustainable flow of about 1300veh/h at the terminus treatment determined the overall 2+1 lane sections capacity. This is a much lower flow than a single lane can usually carry e.g. 1800 veh/h, (i.e. at LOS E) so, care is needed with these treatments.
- Widening weaving areas on motorways can cause more congestion and more serious crashes as a result of drivers having increased options for lane changing. This increases the number of possible conflict points leading to increased turbulence, which is the precursor for crashes "Event as Exposure". While the original intent of these road widenings are often to reduce crashes and relieve congestion they often increase complexity for drivers and increase crash risk, refer Figure 79 Number of conflict points in relation to Lane numbers. However there are often good solutions to widening these weave areas by separating and channeling the majority of the through traffic into their own bypass lanes.

When it comes to international road safety research we need to understand principles that can be applied to our own Australian research rather than copying programs. Australia should no longer be simply comparing (i.e. Australian rural motorways to German autobahns) or, transferring overseas programs as our problems are unique. Context differences include mode splits, distances travelled, fleet composition, climate, daylight/night time durations, tyres type used in winter etc. and, use of roads are very different to many of the countries that have "better" road safety outcomes than Australia.

1.5 The problem of changing circumstance – research becomes outdated

What may have been true for road safety in 1970 or 1990 or even 2005 may no longer be true for road safety in 2017 across all road types, for all hours of the day or for all drivers or for all vehicle classes. For example, there are published reports that large four wheel drive vehicles do not represent a significant problem for road safety in Australia. However when studying police records on a Victorian urban motorways (2017) this can no longer be considered to be the case as they are involved in up to 22% of FSI crashes on urban motorways.

One of the more recent national studies on 4WD (2007) used crash data from a period in Australia dating between the late 1980s to the early 2000s. This no longer reflects the vehicles that are typically more powerful and appear to drive more like a car (i.e. smoother, quieter, have better transmissions to transfer power faster to gain speed etc.). While useful for historical reference, they can no longer be relied on to inform current policy or programs. Another example are the Crash Reduction Factors used in programs to determine the benefits of road safety treatments, where if they were determined more than 5-10 years ago they are unlikely to be relevant to today's problems due to the rapid changes in transport described in Section 6 The Rapidly Changing Context of Urban Motorways.

The last decade in Australia has seen a large growth in the sales of the larger 4 wheel drive vehicles which are now the most common vehicles sold. Larger SUVs are popular family cars, and are routinely driving in urban areas as well as on rural main roads as a weekend getaway vehicle. This is not the case in most of the European cities visited as part of Churchill Fellowship where larger 4WD vehicles are notably conspicuous by their absence, although beginning to grow in popularity.

Currently Australians are buying many more larger SUV/4WD vehicles per annum refer Figure 33 Showing increases in the sales of larger SUV vehicles in Australia. There is a clear trend towards increased sales of these SUV type vehicles and the commensurate reduction in large, light and micro passenger vehicles. This is another reason why European Road Safety Programs cannot be translated directly to Australian context.

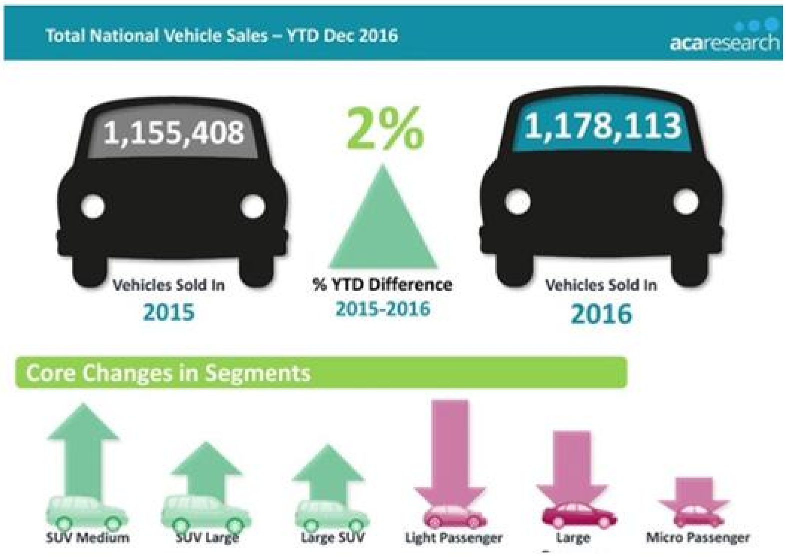
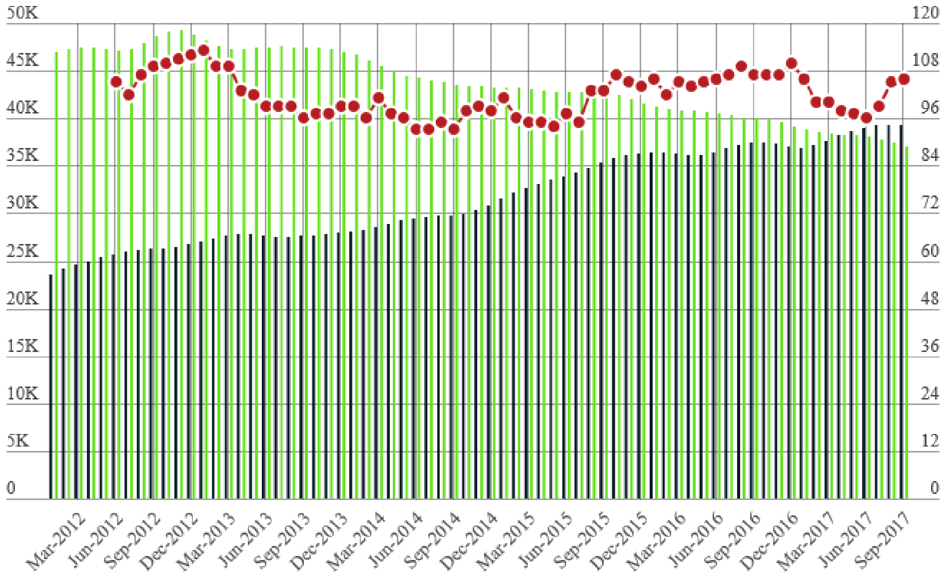


Figure 92 Showing increases in the sales of larger SUV vehicles in Australia

This change in vehicle size, shape, weight and handling performance may have some impact on crash risk in certain circumstances. For example, motorway and highway driving at higher speeds and particularly when combined with heavy traffic conditions, refer Figure 34 showing ABS sales of new motor vehicles September 2017 and road deaths Australia September 2017. Whilst it might be argued as yet that no clear relationship has been established in relation to these larger vehicles and increased crash risk, the author suggests that many of the issues raised in this report collectively can explain why the Australian road toll has stabilised rather than continued to fall as expected. There is a clear change in both trend and road transport context.



SUV sales are shown in blue (left axis): Passenger vehicle sales shown in green (left axis): Road deaths shown in red (right axis)

Figure 93 ABS sales of new motor vehicles September 2017 and road deaths Australia Sept. 2017

1.5.1 Traditional "black spot" analysis only useful for spatially systematic problems

It should be noted that "Blackspot: and "Black Length"[239] treatments have been considered to be appropriate tools over the past 30 years where there were a large number of dangerous locations with very high numbers of similar crash types in any 3-5 year period. However, the changing context at least in urban motorways has resulted in much lower numbers of crashes at any given site or road length, as crashes tend to be both dispersed and linked to temporal traffic loadings and conditions.[240] The following statement from a draft AustRoads report sums this up clearly, further highlighting the changing nature of the problem that seems to require a significant change of approach.

"The relative rarity of fatal and to a lesser extent serious crashes occurring at the same site is evident in an analysis of crashes in Auckland. Analysis of crash data at intersections in 2013 showed that 79% of fatal and serious crashes occurred at sites with no fatal or serious crashes in the previous 5 years and, 64% of crashes occurred at sites with two or fewer injury crashes in the same period. Investing heavily in "Black Spots" programs is unlikely to achieve a step change in road network safety simply because "Black Spots" treated represent only a very small portion of the overall safety problem at the network level"[241]

The current context reveals many road crashes occur somewhat indiscriminately in relation to geometric or infrastructure provision. New understanding is emerging that the geometric of the road and road design factors may play a lesser role in the crash causation, as many of the FSI crashes occur during medium to high traffic volumes and, as a consequence are systematically related to the dynamic traffic loading and unique conditions they present. Significant evidence is emerging that there are several traffic density classes" or "Traffic States" associated with high crash risk and,

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[239] Or new language emerging "Grey Spots"

[240] Where there are high numbers i.e. greater than 5 crashes in 5 years, of very similar crash types over a short section of motorway (200-300m) the traditional "Black Spot" identification and treatments methods may still be a valid course to follow.

[241] Refer SAG2090 Best Practice in Road Safety Infrastructure Program Draft Report assessment in relation to monitoring and evaluation of Road Safety Programs

consequently road safety analysis and interventions need to be extended to incorporate the changing nature of many road crashes.

Traditional macro level crash studies of spatial road crash data (e.g. black spot and black lengths) on urban motorway, is considered unlikely to lead to significant new insights or major breakthroughs to significantly improve their safety. This statement will be significantly true for locations where there are less than five crashes of the same or similar type occurring within any five year period.

1.6 The problem of the narrative bias (Myth busting)

The study of "narration bias" concludes that: "Humans have a strong tendency to rely on narratives to understand the world or to explain it to others. This tendency is so strong that we actually make up explanatory stories based on even the flimsiest of foundations".

This human "pattern-seeking" tendency is referred by psychologists to as "narrative bias" The definition of the "narrative bias" *refers to people's tendency to interpret information as being part of a larger story or pattern, regardless of whether the facts actually support the full narrative*.

There are two specific story elements that are especially strong influences on our behaviour, and likely to trigger biased conclusions being:

1. **Specific details**, which make a narrative realistic and memorable;
2. **Cause and effect explanations**, which help us understand why certain events lead to final outcomes.

"Humans generally aren't great at reasoning objectively about uncertainty or random events as we go about our daily lives. We have a universal desire to find meanings and patterns everywhere. Humans appear to be programmed to try to look for patterns because that is how they navigate the world around them, and to some small degree, control it" (Today).

Given the response of other industries major contribution to road safety[242] and "The Problem of Attribution" discussed above, where the massive contribution of medical, Telecommunications, vehicles design, road design[243], traffic engineering, are largely ignored and not included in the following illustrative story (narrative) shown in Figure 94 Example of narration implying a direct scientific link btw interventions and outcomes. Whilst no one is saying all these messages are not useful, however, they only tell a very small part of a much bigger narrative. Hence the implications from the time series of the road fatalities and the times series of interventions can be combined in such a way to imply the effectiveness of various road safety initiatives, which is overly simplistic and potentially a highly misleading narrative and, yet it is believed by many to be absolutely true.

Unfortunately, random or indiscriminate events cannot be easily explained by humans as to why these things happen. "***Since the human urge for explanations of events is automatic when an unpredicted event occurs, we immediately come up with explanatory stories that are simple and coherent. Our intuitive mind is the sense-making organ, which sees the world as simple, predictable, and coherent. This coherence makes us feel good, but may not provide the correct interpretation for dealing with this new information."***[244] Hence humans can be fallible and this often leads to the wrong outcomes and in the case of road safety less than optimum practices and

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[242] Refer Append B - An alternative perspective on the road safety narrative

[243] The need for good judgement is often underappreciated in these disciplines as good design is as much an art as a science

[244] refer wiki on narration bias

programs.

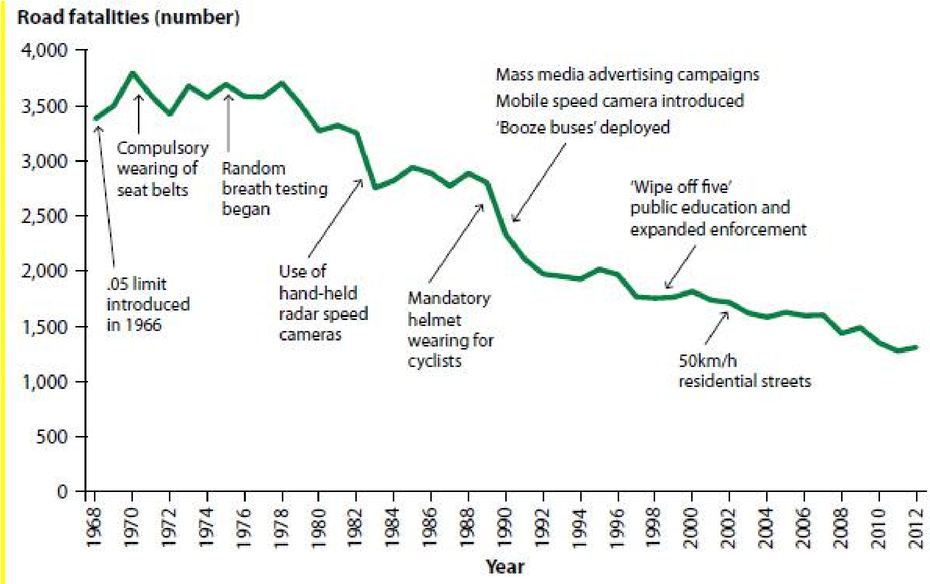

Figure 94 Example of narration implying a direct scientific link btw interventions and outcomes

The book titled Black Swan: The Impact of the Highly Improbable (Taleb) states: *"**When you develop your opinions on the basis of weak evidence, you will have difficulty interpreting subsequent information that contradicts these opinions, even if this new information is obviously more accurate**."* This is an important statement that can hold us back from critical thinking and learning new concepts quickly and, why many organisations and institutions are often slow at responding to changing contexts and circumstances despite the new evidence. Often the organisation's leadership is entrenched in the old narrative as they are both philosophically entrenched and they are on the public record as promoting a certain position or view.

It is important therefore that we recognize this built-in human condition of mental bias. This is essential in road safety as events do not come labeled as being random. Instead, randomness must be inferred and when we study road crashes they do not always neatly fit neatly within a simple predictable stories or patterns. Every road crash is uniquely different and has a different circumstance and cause, which usually involves a complex matrix of contributing factors for which only a few of these factors are possible to analyse from the limited data currently collected about the crash. However crashes can be simply categorised into types or patterns and as such their circumstances, and causation are many and which are often uniquely complex and do not fit into simple classifications.

There may be a dozen or more common reasons as to why a vehicle typically runs off the road at any random location or crashes into another vehicle. We must understand each of these causes in detail, **otherwise, our effort will continue to focus on addressing symptoms rather than finding the cause(s) which leads to cure(s)**. As humans beings like to group items into simple classifications based on only a few of the factors (i.e. by seeing simple patterns) such as the common grouping the "run off the road crash", in order to provide simple explanatory stories to explain the problem(s) to others. Thus our solutions often fit into categories of simple patterns which often produce simplistic solutions when all crashes have complex and quite varied causes.

New paradigms or narratives are urgently needed in the field of road safety as abnormalities (e.g. "Events of Exposure" as "Nucleation Events") are being discovered which challenge current scientific methods and strategies. Now that the Australian and many other first world country's FSI crashes appear to no longer be reducing, new understanding and solutions are required and hence the old narrative needs revision sooner than later. **Thus the honesty of many European researchers who admitted they don't know why crash numbers have risen means their minds were open to the possibilities of new paradigms, rather relying on the old narrative to interpret the current abnormalities**. They were open to the fact that context was changing, something was clearly disrupting current understanding and requiring some correction to the current trajectory of road safety programs and supporting narratives.

Another excellent technical resource brought to my attention during the Churchill Fellowship including:"The Structure of Scientific Revolutions" by Thomas Kuhn ***"where scientific analysis or normal scientific progress is viewed as development by accumulation* (of knowledge) however, Kuhn argues *"normal science is interrupted by the discovery of "abnormalities" which leads to new paradigms"***.

1.7 The problem of simple explanations (Myth busting)

My experience over 30 years in transport is that there has often been many simple stories, stereotypes and arguments used in public forums and the media to explain why crashes occur. Often these simple messages can discriminate entire age groups (e.g. young and old) when only a subset of this age group needs to be targeted. Or they focus on only a few of the many issues that contribute to road crashes (e.g. targeting speed, drugs or alcohol).

Road safety messages are only snippets of the complexities involved in road crashes. Good drivers are involved in FSI crashes . All drivers make mistakes and can be involved in serious crashes, whether theses mistakes are made by us or by others. The majority of the FSI crashes are caused by those who consider themselves to be responsible and safe drivers – so simple road safety messages don't relate to them.

A few examples of simplistic messages and some myths that need to be challenged include:

Motorways are not a significant road safety problem – *the data shows casualty crash numbers are rising and the number of crashes is now significant. The number of persons injured per crash are higher than on other roads.*

Urban motorways are safer than urban arterial roads so put more traffic onto the motorway – *this is not true at all times of the day (i.e. when the motorway flows are moderate to heavy or become moderately congested), the motorway becomes quite dangerous with FSI crashes. Motorways don't gradually decay they suddenly fail and become dangerous with a multiplier (e.g. 3-6 fold) effect with increased risk of FSI crashes.*

The problem with motorways is speed and alcohol crashes at 2-3am – *this is no longer true although it may have been true 10-20 years ago and still true in some parts of the world that have not focused on speed enforcement or alcohol to the same level as Australia.*

Young drivers are dangerous drivers *–This may only be true for a very small percentage of younger* *drivers. Refer report from SWOV Netherlands by Dr W.P. Vlakveld title translated to English as Driver Age Disentanglement (2005) which shows the younger a driver starts to learn the safer they are over their lifetime. Quite a different positive messaging about younger drivers could be used rather than the usual stereo type negative messages relating to a small percentage of youth. Advertising campaigns might be disengaging the majority and not targeting the problematic core commonly indicated on the Churchill Fellowship as the 5% who have lower levels of responsibility and maturity.* Figure 37 *shows that younger driver who travel more than 14,000 km per year are the safest drivers of the road and they are reasonably safe if they drive more than just 3000km per year. .*

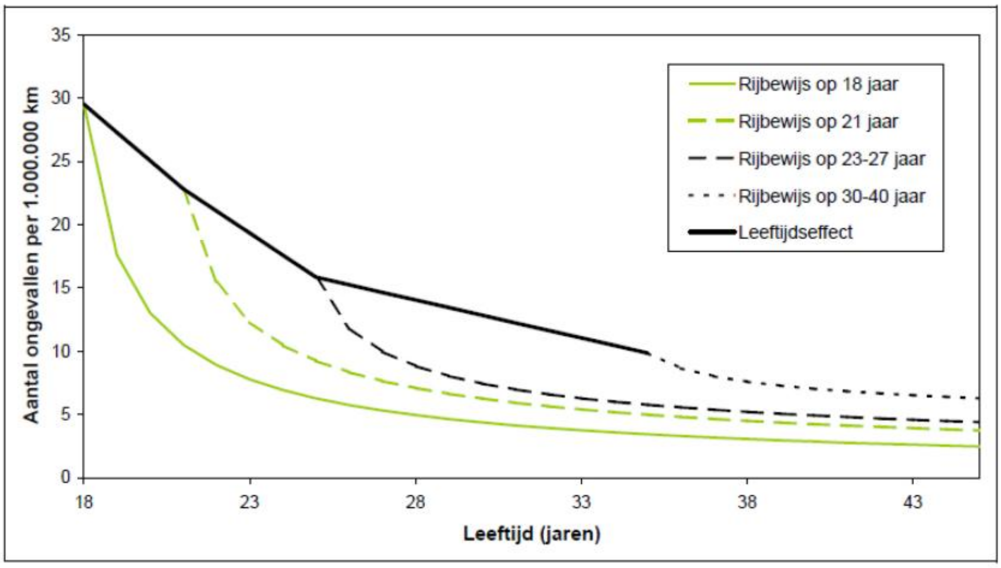

Figure 95 Relationship btw age of learning to drive and crash involvement

Old drivers are dangerous drivers – *This appears to be only amongst those who drive less than 3000km per year otherwise it appears they are much safer. Refer* Figure 96 Annual crash involvement for different driver ages, controlling for annual mileage *which implies this is only the case if they drive less than 3000km per annum*

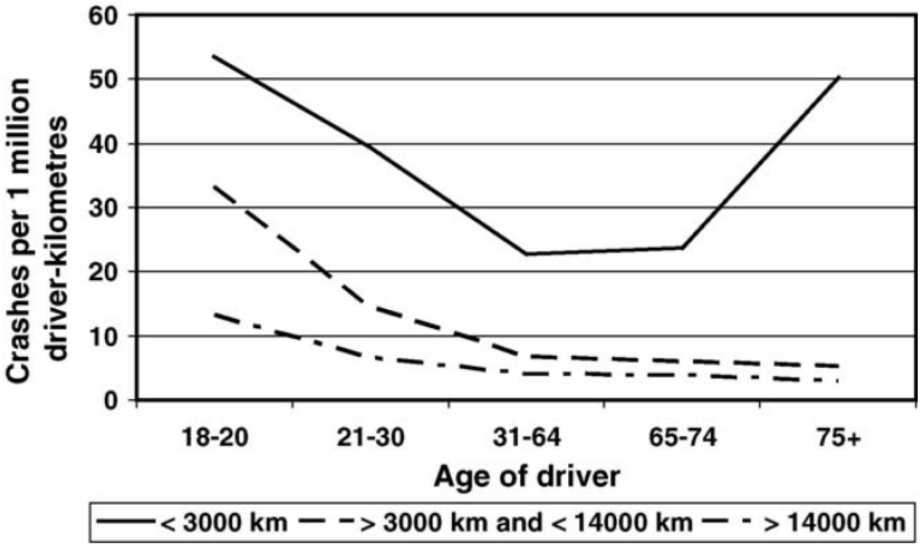

Figure 96 Annual crash involvement for different driver ages, controlling for annual mileage

The problem with motorways that people can't merge or drive at the speed limit. This complaint is often expressed by the faster and more aggressive drivers. *It is often the faster and more aggressive drivers who trigger the crashes where someone else gets seriously injured and hence VTI psychologists indicated that the faster more aggressive drivers needed to be specifically targeted in road safety messaging, far more than has been done previously. These are usually the drivers who regularly drive at or slightly above the speed limit (.e.g. 105km/h), and often maintain short headways (e.g. tailgating) and complain about slower drivers travelling above 95km/h impeding their journey in their lanes. Such behaviours have not been the subject of "bad driver" campaigns and, hence this type of behaviour seems to be openly encouraged as these views seem to be tolerated and are regularly a topic in the media and on talkback radio etc. highlighting that slower drivers are always the problem when evidence might now be suggesting it is the other way around.*

Red light cameras are effective at reducing crashes at signalized intersections – *potentially contradicted by Australian leading accident research centre's reports that do not show statistically significant findings in relation to this claim e.g.* (Andreassen, 1995), (Sally Kent, 1995) & (CN Kloeden, 2009) *and hence the latter more recent report 2009 suggested putting in speed cameras at traffic signal as well which has now become common practice. Are all these reports scientifically flawed? We must let the readers of these research reports decide whether the science holds.*

Easter and Christmas are dangerous periods on our roads – *several reports by the Australian Federal Government proved this not be the case statistically. Pronounced year to year fluctuations in the data suggest that the number of people killed in any given holiday period is significantly influenced by random events. An analysis of average number of deaths per day found that fatality rates during holiday periods were not systematically higher or any lower than fatality rates at other times of the year. These studies also found no evidence of any change in the involvement of primary causal factors (speeding, alcohol or fatigue). The findings are broadly consistent with the results of a similar study undertaken in 2003. (Bureau, 2006)*

1.8 The problem of rare disruptive events

Nassim Nicholas in his book The Black Swan: The Impact of the Highly Improbable' (Taleb) states that:

"*Before the discovery* (of the "Black Swan") *in Australia, people in the old world were convinced that all swans were white, an unassailable belief as it seemed completely confirmed by empirical evidence. The sighting of the first black swan might have been an interesting surprise for a few ornithologists (and others extremely concerned with the coloring of birds), but that is not where the significance of the story lies.*

This illustrates we often have a severe limitation to our learning from observations or experience and the fragility of our knowledge. ***One single observation can invalidate a general statement derived from millennia of confirmatory sightings of millions of white swans****."* Thus all you need is one single outlier (i.e. a blackbird), to change the course of history, our thinking, and our direction.

What Taleb calls a "Black Swan" event is an event with the following three attributes.

- *First, it is an outlier, as it lies outside the realm of regular expectations because nothing in the past can convincingly point to its possibility.*

- *Second, it carries an extreme impact.*
- *Third, in spite of its outlier status, human nature makes us* **concoct explanations** *for its occurrence after the fact, making it explainable and predictable.*

Taleb states *that from the triplets:* ***rarity, extreme impact, and retrospective predictability*** *a small number of "Black Swans" can explain almost everything in our world, from the success of ideas and religions to the dynamics of historical events, to elements of our own personal lives. The effect of these "Black Swans" has been increasing as it* "***started accelerating during the industrial revolution, as the world started getting more complicated, while ordinary events, the ones we study and discuss and try to predict from reading the newspapers, have become increasingly inconsequential***".

"Our inability to predict outliers implies the inability to predict the course of history, given the share of these events in the dynamics of world events". It is often shown, for example, predicting long-term global political outcomes or even long-term government budgets forecasts, which often become inaccurate after only a few financial quarters and are very difficult to predict as "Black Swan" events arise regularly. This thinking seems to align with where the first world has arrived at in road safety where the trend of the past 30 years is now being disrupted in a number of ways and thus we are now at the stage devising (concocting) plausible explanations for its occurrence, "**making it explainable and predictable**" only after the fact by saying it might be caused by this or that, refer "Narration Bias" above.

As discussed above when outliers "Black Swan" events occur in data or analysis, these findings tend to be initially ignored by researchers as outliers and explained away by the narrative as not being consequential to the problem at hand, thus getting passed over. This trait is also discussed in "Publication Bias" where zero results and results that don't support the hypothesis or sponsors expectations are often discarded and/or not published. Common approaches in reports to explain such findings is not to publish the findings at all as they are counter to the narrative and which tend to use statements in the reports such as ***"due to limited data and difficulties with the evaluation design for these projects, the evaluation was generally unable to draw conclusions about the effectiveness of these treatments***". So the results are not published further biasing research findings. As Rune Elvik puts it ***"the results of road safety evaluation studies that initially strike us as counterintuitive, can usually be given some ad hoc and post hoc explanation and often are dismissed as aberrations".***

For example, on motorways for many years traffic data at the 20 second time interval was considered by researchers to be too noisy to make sense out of or use in their analysis. However, currently the 20-second data is revealing the essence of modern traffic theory and now is considered so important we are beginning to look even closer at the 1 second time interval. At this level of aggregation, it is possible to see the random clusters of vehicles which cause the very high traffic densities that are the pre-conditions "Events of Exposure" that rapidly increase the crash risk on motorways and has changed the way we understand traffic theory.

Data that was ignored and discarded for decades is now considered to be the "Black Swan", and fundamental to understanding the current road safety problem of rising crash rates. Understanding that we are dealing unpredictable (i.e. rare or random events) has been the basis of contemporary traffic flow theory where the traffic capacity (i.e. the volume of a road), can no longer be considered predictable. It requires an associated probability to be measured and quoted alongside the capacity value to enable it to be understood by quoting the traffic volume's behaviour, (i.e. likelihood of the value being achieved or sustained in practice). Accommodating and making allowances for the unpredictable in our often closed mindsets, theories, methodologies, statistical methods and assessment of risks will open us to new understanding and discoveries and faster acceptance of outliers.

1.9 The problem of whether theory can explain analysis

In reviewing the extent to which road safety evaluation research is based on engineering solutions or behavioural theories, Rune Elvik (Rune, To what extent can theory account for the findings of road safety) noted that:

> *"...**historically much of research is not based on behavioural theory, and mostly refers to it only informally or not at all".***

Rune argues *"that most road safety measures have to influence human behaviour in order to be effective. Seat belts must be worn in order to protect from injury; headlights must be turned on in order to make the car more visible; drivers must stop at red traffic signals for these to function as intended, and so on. It is, however, not always the case that human behaviour needs to be influenced for a road safety measure to be effective. Road lighting, for example, does not require road users to change their behaviour in any way. Guardrails and other energy absorbing structures fitted to roads or vehicles protect road users from injury, while not requiring that road users modify their behaviour in any way. However, road safety evaluations in the main would be incomplete without quantifying the effects on human behaviours or road safety initiatives". Behavioural theories must:*

1. *Serve as the basis for designing roads and vehicles that are optimally adapted to human limitations with respect to perception, the possibility of making errors and the consequences of erroneous action,*
2. *Serve as the basis for regulating human behaviour within a given technical system in a way that is conducive to road safety,*
3. *Propose hypotheses about human behaviour to be tested in studies designed to evaluate the effects of road safety measures,*
4. *Specify the behavioural mechanism through which road safety measures are intended to affect safety, and*
5. *Specify possible unintended behavioural adaptations to road safety measures, which may in part or in whole offset the effects of those measures on safety."*

Logically speaking, a road safety measure must influence one or more risk factors that are associated with accident occurrence or injury severity, in order to reduce the number of accidents or the severity of injuries. In an earlier paper (Elvik 2001), the concept of a "causal chain" was introduced in order to describe the process through which a road safety measures affect safety. Rune Elvik, therefore, proposed 8 generic risk factors for road accidents and injuries that are normally targeted for influence by means of road safety measures. These factors serve as the basis for modelling the engineering effect and behavioural effects of all road safety measures. It is proposed that all risk factors can be reduced to one or more of these general types:

1. Kinetic energy

> *The movement of people and vehicles produces **kinetic energy**. The amount of kinetic energy produced is a function of the mass of a body and its velocity (speed) (Noon 1994): E = ½ mv2. This basic law of physics identifies the speed and mass of a vehicle as basic risk factors for*

accidents. However, kinetic energy is a hazard only. It does not cause harm as long as it is controlled.

2. Friction

When control of the movement of a body is lost, the possibility of bringing the body to a stop is decisive for avoiding accidents or reducing injury severity. Hence, the ***friction*** *between vehicles and the road surface should be considered a basic risk factor for accidents.*

3. Visibility

Another basic risk factor is ***visibility****. Visibility is the possibility of seeing something at a distance. The greater the distance at which an object can be seen and identified, the greater is visibility.*

4. Compatibility

When different vehicles or road users crash, their compatibility in terms of mass and speed exert a decisive influence on the outcome of an accident (Harms 1992). Compatibility refers to the differences between categories of road users in terms of the kinetic energy produced by their movements. The smaller these differences, the more compatible are road users. One way of reducing incompatibility is to separate in time or in space groups of road users that are highly incompatible.

Speed, vehicle mass, friction, visibility, and compatibility are all risk factors that are closely related to the physical laws governing the movement of bodies across a surface. It is often argued, however, that human factors represent most important risk factors for road accidents. The taxonomy proposes to reduce the very many human factors that contribute to accidents specifically:

5. Complexity

Complexity is a property both of the traffic system and of traffic as such. Complexity refers to the amount of new information a road user has to process per unit of time. In dense urban traffic, complexity will typically be high, because road users have to pay attention to a rapidly changing traffic situation, in addition to performing the usual perceptual-motor tasks of walking, cycling or driving a motor vehicle.

6. Predictability

Predictability denotes the reliability with which the behaviour of a road user can be predicted in a given situation. Lane-keeping is an example of very predictable behaviour. When driving on an undivided two-lane road, most drivers do not expect oncoming traffic to suddenly enter their own driving lane – and most of the time this prediction is correct.

7. Individual rationality

Individual rationality refers to the extent to which road users behave in ways that satisfy their preferences (maximise utility). In the context of road safety rationality can be defined as the ability of road users to correctly perceive hazards and take appropriate action to prevent hazards from developing into accidents. This definition of rationality assumes that nobody wants to become involved in an accident. Hence, to the extent that road users are able to act rationally, accidents will be avoided. Factors that may inhibit rationality include both elements of roads and vehicles (badly designed roads and vehicles increase the likelihood that errors will be made) and the state of the individual. Excessive consumption of alcohol or *drugs, lack of sleep, illness or other more or less permanent individual traits may inhibit rationality*

8. Forgiveness

Forgiveness denotes any element of roads or vehicles that either prevents errors made by road users from leading to accidents or that absorbs energy in case an accident occurs, thus making serious injury less likely. Forgiveness is typically built into roads by making them wider, by installing rumble strips, or by installing guardrails or crash cushions. Cars are made more forgiving by having seat belts, airbags, collapsible steering columns, laminated windshields, and so on.

1.10 Concluding remarks

This Section raises many issues that are known to most researchers and for part of their formal training but are still being overlooked. There may be a need to develop national guidelines to standardise methodologies and statistical methods, with a simple framework for assessing road safety evaluation studies.

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