SERIOUS INJURY CRASHES

How do they differ from fatal crashes?
What is the nature of injuries resulting from them?

MACKIE RESEARCH
OPTIMISING HUMAN SYSTEMS

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
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Authorship: This document was written by Hamish Mackie, Richard Scott, and Lily Hirsch from Mackie Research, and by Pauline Gulliver and Shanthi Ameratunga from Auckland University. John de Pont from TERNZ provided internal review and analysis advice. For further information, please contact Hamish using the contact details below

Physical address	Postal address	Contact
Level 2 Princes Court	PO Box 106525	Hamish Mackie
2 Princes street	Auckland City	MB: 021 067 0337
Auckland 1010	Auckland 1143	Email: hamish@mackieresearch.co.nz
		www.mackieresearch.co.nz

EXECUTIVE SUMMARY

Background

There is a gap in the knowledge about light vehicle crashes in NZ. Currently, there is limited understanding of the differences in system failure between fatal crashes and those that result in serious injuries. Serious injury crashes can also involve a wide range of outcomes ranging from less severe injuries to life threatening trauma that may have long-term consequences. However, we know little about the proportions and nature of more severe injuries and less severe injuries, therefore the human cost of these injuries is unknown. Serious injuries are important as they account for the greatest proportion of the social costs from New Zealand's road trauma.

To assist in filling these knowledge gaps, two studies into serious injury crashes have been conducted: Part 1 How do serious crashes differ from fatal crashes; and Part 2 The severity and type of injuries suffered by those involved in serious crashes. Part 1 compared the circumstances of serious and fatal crashes, using a Safe System analysis framework, including the proportion of crashes where 'reckless behaviour' was exhibited. For Part 2 the goal was to develop a profile of road crash injuries to better understand the proportion and nature of serious injuries that involve life-altering trauma, compared with less-extreme injuries like a broken bone.

Part 1

Following a scan of literature to guide the method, a Safe System analysis framework was developed, tested, and applied to 200 serious injury crashes and 100 fatal crashes involving light vehicle occupants. This included criteria for 'triggering' each system pillar. For the User pillar 'reckless behaviour' was also identified using an agreed set of criteria and for the other pillars extraordinary factors were also identified.

For both serious injury and fatal crashes there was significant involvement by all four pillars of the Safe System across the 300 crashes but serious injury crashes were less likely to involve all four pillars of the Safe System. This is a real-life reflection of system theory which proposes that high severity incidents happen when multiple system failures come together without remaining defences to mitigate the impacts.

Other notable findings were that fatal crashes had a higher proportion of roadside objects and other vehicles struck, were more likely to involve narrow shoulders for run off road crashes, were more likely to involve centreline crossing crashes on 100 km/h roads and typically happened in higher speed environments. New vehicles typically had better outcomes in two-vehicle crashes and SUV's/4WD's and Utes were more likely to roll-over. Consistent with overseas literature, reckless behaviour was a contributing factor in more fatal (47%) crashes than serious injury crashes (30%). Finally, multiple system failures were evident across the majority of fatal (99%) and serious injury crashes (93%).

Part 2

The investigation highlighted the difficulty of answering what may appear a relatively simple question: “what is a serious injury”. Seriousness can be defined in terms of threat to life, the long-term impact on an individual’s quality of life, length of stay and cost of medical care, and / or long term psychological impact. The analyses presented in this report focuses on the concept of threat to life.

Two hospitalisation datasets - the National Minimum Dataset (NMDS) and Auckland Hospital’s Trauma Registry (AHTR) - were used to provide a baseline understanding of the distinguishing features of serious and less serious motor vehicle traffic crashes resulting in injuries that require hospital admission. This is designed to provide a deeper understanding of many of the crashes that would normally be categorised as “serious” using the CAS definition.

It is important to acknowledge that the concept of serious injury, when viewed from a medical perspective, is more complex than the CAS definition of serious injury. Injuries that can result in immediate threat to life are commonly perceived as ‘serious’, but injuries that are not a significant threat to life can result in long-term disability (an aspect of injury severity that is not covered by this study). Nevertheless, hospital admissions that would typically be classed as ‘serious injuries’ by CAS are also on a continuum that ranges from lower to higher threats to life.

Approximately 15% of motor vehicle related hospital admissions have a high threat to life. Almost always, these admissions involved multiple injury types (such as a combination of punctured lung, spinal fracture, and head injury). One exception is brain injuries. A brain injury was found to be a determining factor of threat to life, irrespective of the nature and severity of other injuries present, and even in the absence of other injuries. The majority of AHTR cases involved severe or critical head, neck or cervical spine injuries.

In this investigation of on-road injury events, most people with high threat to life injuries were car occupants, motorcyclists, people less than 25 years or greater than 45 years, and males. Among car occupants, high threat to life cases more often involved serious injuries to the sternum, vertebrae, or brain whereas lower threat to life cases tended to involve a wider range of locations and less severe diagnoses e.g. unspecified injury of neck, sprain or strain of cervical spine or unspecified injury of abdomen, lower back, and pelvis. Among motorcyclists, common diagnoses in high threat to life cases were serious bone fractures (shaft of femur, multiple ribs) and serious head and thorax injuries, while the lower threat to life cases involved less serious bone fractures and open wounds. In general, high threat to life cases across all road user groups involved injuries that are consistent with higher forces impacting the body. This aligns with the findings of Part 1 regarding the influences of higher speed environments and crashes involving impacts with roadside objects or other vehicles.

It is interesting to note that, based on the Auckland Hospital Trauma Registry (AHTR) data, lower threat to life injuries, as a proportion of all injuries in this study, have been increasing in recent years. We can only speculate on the likely reasons for this trend. It is possible that the pattern is unique to the Auckland region. However, further analyses using national trauma data sets would be required to establish if this is the case. While the classification of severity is different, analyses of the NMDS suggest that low threat to life injuries in NZ more generally have declined while high threat to life injuries have been relatively static in recent years.

Conclusions

Both parts of this report suggest that system factors need to be considered together. Multiple system factors are often implicated in more serious and fatal crashes, but one or two system 'safety nets' may be all that is needed to prevent major trauma. This may be more difficult in extreme crash situations where, for example, very high speeds are present or collisions with non-frangible objects happen when occupants are unrestrained. There are clearly crash scenarios that are more likely to lead to high threat to life injuries and fatalities and this understanding should be driving measures to reduce road trauma. Further work should link these various datasets and this may be feasible once CAS data is included into governments' Integrated Data Infrastructure. More work to understand the latent system conditions that precede crashes, as well as the longer-term outcomes from certain crashes, including disability and loss of opportunity, would also be useful.

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INTRODUCTION AND BACKGROUND

There is a gap in the knowledge about light vehicle crashes in NZ. Currently, there is limited understanding about the circumstantial differences between fatal crashes and those that result in serious injuries. Previous analyses suggest that there could be considerable differences in the nature of fatal and serious crashes (Stigson, Kullgren et al. 2011, Wundersitz and Baldock 2011), which may have implications for initiatives aimed at reducing road trauma. Furthermore, analyses to date based on Crash Analysis System (CAS) data typically report isolated factors associated with crashes and do not take a Safe System view. There is a need to more holistically analyse crashes with all aspects of the system in mind.

Serious injury crashes can also involve a wide range of outcomes ranging from less severe injuries to life threatening trauma that may have long-term consequences. However, we know little about the proportions and nature of more severe injuries and less severe injuries, therefore the human cost of these injuries is unknown. Furthermore, the overall trauma resulting from serious injuries continues to burden New Zealanders as the number of serious injuries has not declined in recent years. Serious injuries also account for the greatest proportion of the social costs from New Zealand’s road trauma.

To assist in filling these knowledge gaps, two studies into serious injury crashes have been conducted: Part 1 How do serious crashes differ from fatal crashes; and Part 2 The severity and type of injuries suffered by those involved in serious crashes.

Scope

The research questions for these two parts were as follows:

For Part 1, the research questions were:

- Are there differences in the circumstances that lead to fatalities or serious injuries in New Zealand’s light vehicle crashes?
- What proportion of crashes result predominantly from system factors as opposed to reckless behaviours?

For Part 2 the goal was to develop a profile of road crash injuries to better understand the proportion and nature of serious injuries that involve life-altering trauma, compared with less-extreme injuries like a broken bone.

For ease of comprehension, the method, results, and discussion of each Part are presented separately to reflect the nature of this two-part study. The related findings from each part are brought together in the summary.

PART 1
THE NATURE OF SERIOUS INJURY CRASHES AND HOW THEY DIFFER FROM FATAL CRASHES

1.1. Introduction

The Safe System approach emphasises, among other concepts that: the road environment needs to be more accommodating of human error and people are vulnerable to crash forces. It looks across the entire road system to improve safety by creating safer roads and roadsides, safer speeds, safer vehicles and safer road use (Ministry of Transport 2010).

Although there have been many road safety analyses based on CAS data they typically focus on single factors (e.g. speed, trucks, or pedestrians) and do not focus on the combined contributions of the various pillars of the Safe System for single crashes. While CAS has its limitations, there is potential to gain deeper insights into crashes if a more holistic view is taken. Furthermore, there is the potential to complement CAS information with other available data such as ANCAP ratings from the RightCar website, and speed and road risk information from the Speed Management Programme GIS database.

The approach for this research was conducted in two phases. This involved a literature scan, and an analysis of various data including the Crash Analysis System (CAS), to better understand the nature of serious injury crashes, compared with fatal crashes.

1.2. Literature scan to inform method

Firstly, a brief scan of the academic and non-academic literature was undertaken to determine the methodologies used for studies which compared fatal and serious crashes. Seven studies were used to inform our method. They are briefly described below.

Use of car crashes resulting in injuries to identify system weaknesses (Stigson, Kullgren et al. 2011):

Using a combination of three data-sets (Swedish Transport Administration's database of in-depth investigation, UK On The Spot data, and the Swedish Database STRADA), this study aimed to find the reason for injury (fatal or serious injury) occurrence, rather than the cause of a crash. Therefore, different components and combinations of the system were examined: the road, the vehicle, and/or the road user. For all crashes, the vehicle's safety rating, the presence of electronic stability control (ESC), and whiplash protection systems were examined, and the road was classified according to European Road Assessment Programme (EuroRAP) criteria. Importantly, for each case, two questions were posed: 1) Did the crash involve noncompliance with the road criteria, vehicle criteria, and/or road user criteria?; and 2) For crashes where more than one of the three components do not comply with the safety criteria, are all the components correlated to the injury outcome?

Why do people die in road crashes? (de Pont 2016):

This New Zealand study examined 122 fatalities from 2014-2015 which involved cars, trucks, and motorcycles. Using Traffic Crash Reports (TCR) and Serious Crash Unit (SCU) reports, the crashes were categorised by vehicle type (truck, car, motorcycle), and if they occurred in a rural, or an urban setting.

The relative contribution of system failures and extreme behaviour in South Australian crashes (Wundersitz and Baldock 2011):

The aim of the study was to investigate the relative contribution of 'system failures' and 'extreme behaviour' in South Australian crashes from the 2008 calendar year. The researchers used two datasets: Coroner's investigation files (fatal crashes), and the Centre for Automotive Safety Research (CASR) in-depth crash investigations (serious crashes used- fatal removed). Data were analysed using the following variables: nature of the crash; cause of death; driver, rider, cyclist, or pedestrian factors; vehicle factors; and road and environment factors.

Each crash was examined to determine if it was the result of a 'system failure' (the effect of the road transport system on the crash), an 'extreme behaviour' (a deliberate act i.e. BAC greater than 0.150g/100ml, travelling more than 50% over the speed limit), or an 'illegal system failure' (a slip, lapse, or, error). A degree of personal judgement was used in determining some extreme behaviour events, particularly in relation to seatbelt use, and driving while unlicensed. Whilst the researchers acknowledged that a crash may be the result of a combination of system failures and extreme behaviours, for the purposes of the study, they were treated as mutually exclusive.

The report highlighted that for a large proportion of crashes, the incidence and severity of crash outcomes could be reduced by improvements in the 'system' (i.e. improvements to road system design to serve compliant road users).

Safe system evaluation of the Christmas/New Year Holiday road toll 2016/17 (Mackie and Scott 2017)

Using a Safe System framework, this report examined the road fatalities for the Christmas/New Year 2016/2017 period in New Zealand. To achieve this, TCRs were analysed, the vehicle's safety rating was recorded, the safe and appropriate speed for the road and Infrastructure Risk Rating were identified.

High-risk drivers in fatal and serious crashes (Ministry of Transport 2012)

In this New Zealand-based study, data from 2006-2010 were gathered from the CAS system and were filtered for at-fault drivers (based on the CAS-assigned crash cause factors) only. The report compared patterns of high-risk, at-fault drivers with other at-fault drivers in New Zealand in fatal and serious crashes. The study also used in-depth data pertaining to a person's previous convictions (i.e. repeat alcohol offences, evading enforcement, repeat speed offences).

The Safest System: preventing crashes by preventing errors (Hatfield and Brown 2016):

Data from 94 crashes occurring between March 2010 and February 2013 were obtained. A mixed-methods protocol included interviews with vehicle occupants, and a thorough investigation of the vehicle and crash location using a team of behavioural, road safety, and forensic experts.

Risky driving habits and motor vehicle driver injury (Blows, Ameratunga et al. 2005):

This study used cross-sectional data from the New Zealand Blood Donors' Health Study with the New Zealand Health Information Service's 'National Minimum Dataset' to examine the relationship between risky driving habits, prior traffic convictions, and motor vehicle injury.

The seven studies described above each went some way to informing our method. For example:

- Different components of the system, such as roads, vehicle, and the user were examined (Stigson, Kullgren et al. 2011, Wundersitz and Baldock 2011, Hatfield and Brown 2016, Mackie and Scott 2017);

- The vehicle safety rating was recorded (Stigson, Kullgren et al. 2011, Mackie and Scott 2017);
- A road classification system was used to determine their level of infrastructure risk (Stigson, Kullgren et al. 2011);
- Non-compliant road users were noted, as were the factors that contributed to this status (i.e. alcohol use and speed) (Blows, Ameratunga et al. 2005, Stigson, Kullgren et al. 2011, Wundersitz and Baldock 2011, Ministry of Transport 2012); and
- The use of TCR reports as a data source (Ministry of Transport 2012, de Pont 2016, Mackie and Scott 2017);

Key features from these studies that were not replicated in our method include:

- Road user types. For example, de Pont (2016) included trucks and motorcyclists, and Wundersitz and Baldock (2011) included pedestrians, cyclists, and riders. This study focussed only on light vehicles;
- Many studies included in-depth crash information from a range of sources including SCU reports (Ministry of Transport 2012, de Pont 2016), coroner's reports (Wundersitz and Baldock 2011), New Zealand Health Information Service's 'National Minimum Dataset' (Blows, Ameratunga et al. 2005), forensic examinations of the vehicles (Hatfield and Brown 2016), and interviews with survivors (Hatfield and Brown 2016).

1.3. Dataset Selection

The data were obtained from the Transport Agency's Crash Analysis System (CAS). Within the database are Traffic Crash Reports (TCR), which are prepared by the officer who attended the scene, and Serious Crash Unit (SCU) reports, which are prepared for all fatal crashes, but rarely for serious injury crashes. To ensure the equal comparison of fatal and serious crashes, SCU reports were not used in this analysis.

A crash list was extracted from CAS for the period 1/7/2015 - 30/6/2016. Exclusions were applied so that only fatal and serious crashes, and only drivers and passengers were included in the search. In addition, vehicles involved in a crash were limited to: car/station wagon, taxi, van, or utility, or SUV/4x4. Drivers of light vehicles who are under 16 years of age were excluded from the study. However, under-16-year-old occupants of a vehicle that was driven by someone over the age of 16 were included in the analysis. Whilst motorcycles represent a disproportionately large number of the total fatality and serious injury rates in New Zealand, to simplify the method they were not included in this analysis. This approach was not to minimise the importance of crashes involving these conditions, but rather to focus on a relatively homogenous dataset that would allow meaningful comparison of fatal vs serious crashes.

Using the exclusions described above, a list of 1,289 crashes (197 fatal and 1,092 serious crashes) were generated from CAS. Each crash type was allocated a random number and the first 100 fatal crashes and first 200 serious crashes were selected for analysis. Eight cases were excluded during the analysis: four had insufficient data in the Traffic Crash Report (TCR); two crashes occurred in car parks; one crash occurred due to an illness, with no apparent injuries caused in the crash; and one crash involved a truck that had not been excluded in the initial extraction. To replace those excluded cases, the random number process was used.

1.4. Analysis Procedure

A primary goal for the analysis was to categorise the involvement of each of the four Safe System pillars (Figure 1) for each of the 100 fatal and 200 crash cases, as was recently carried out in a relatively small analysis of Holiday Road Toll fatalities (Mackie and Scott 2017).

Figure 1: Safe System approach to road safety (Ministry of Transport 2010, p.11)

A detailed coding framework was developed, in conjunction with the multi-agency project steering group, to guide the analysis and is shown below in Figure 2.

A secondary goal was to apply the Wundersitz and Baldock (2011) methodology of broadly determining the proportion of fatal and serious crashes that have reckless behaviours as key factors vs those where a relatively equitable contribution of system factors was at the heart of crash outcomes. However, a deviation from the coding framework of Wundersitz and Baldock (2011) was applied. Where Wundersitz and Baldock (2011) used three categories to identify the factors at the heart of the crash ('extreme behaviour', 'system failure', and 'illegal system failure'), in this study only two categories were used ('system failures', and 'reckless behaviours'). The term 'reckless' was chosen as it better reflects the actions of many drivers who, either unusually or regularly, operate outside of the system that is deemed to be safe. A set of rules for reckless behaviour in a crash was determined. There were a range of potential triggers for reckless behaviour (Figure 2), with more serious factors (e.g. more than 20 km/h over speed limit) immediately triggering reckless behaviour, and at least two less serious factors (e.g. 10-20 km/h over the speed limit) being needed to trigger reckless behaviour.

This study was more concerned with the actual contribution of system pillars to crash outcomes, as opposed to those who are acting illegally, which is more useful for prosecution purposes. We hope this reflects a safe and fair system and is a more constructive way to understand crash causation and outcomes.

Prior to the full analysis, the framework was tested by independent analyses of five cases by three of the researchers. Any discrepancies in coding were discussed and solutions agreed.

Figure 2: Coding structure for CAS analysis

Apply random number to all crash cases from 2015-2016 → Only include single car, or car to car crashes → Exclude cases where TCR form is incomplete i.e. diagram or description of the crash missing → Exclude drivers under 16 year of age → Keep a record of excluded cases → If unsure, team to review

Crash Information

TCR coding

- Time of day
- Date, Day of week
- Crash ID no.
- Dark, overcast, Bright sun, twilight
- Person injured driver/ passenger/ M/F, age
- Serious/ Fatal
- Weather- Fine, Heavy rain, Light Rain, Mist
- Road surface – Wet, Dry, Ice/snow
- Traffic control – Stop, Give Way, Signalised
- Crash movement

Speed

TCR coding

- Speed limit
- Speed advisory
- Primary vehicle speed *(if available)*
- Other vehicle(s) speed (if present)

Other Data coding

Safe and appropriate speed (SAS)

Speed Pillar Trigger (one or more):

- SAS < speed limit
- SAS < travel speed
- Speed advisory < travel speed
- Top 5% priority for speed management

Extraordinary speed factors:

Team to review: Any information in the TCR report that leads to extraordinary speed factors.

Vehicle

TCR coding

- Vehicle age
- Make
- Model
- Did it roll Y/N
- Vehicle type: Ute/Van/ 4WD/Car/SUV
- Other vehicle (Age, Type, Make, Model)
- WOF: Y/N/U

Other Data coding

- Right Car Star Rating (USCR/ ANCAP/ ENCAP)
- ESC equipped Y/N/U
- Car has front airbags Y/N/U
- Car has side airbags Y/N/U
- ABS Y/N/U

Vehicles ≥ 14 years old checked for Star ratings and safety features (where available)

SCU data will not be used, ensuring equal comparison of fatal and serious crashes

Vehicle Pillar Trigger (one or more):

- Vehicle ≥ 14 years
- No front airbags (if head on crash) *if data available*
- No side airbags (if side crash) *if data available*
- Rating 1-3
- No ABS *if data available*
- Any other stated vehicle defects

Extraordinary vehicle factors

Team to review: Any information in the TCR report that leads to extraordinary vehicle factors i.e. four bald tyres.

Roads and Roadsides

TCR coding

- Crash location:
  - Intersection type – X,Y T- junctions, Roundabout, Driveway, Multi road join
  - Straight/ curve
  - Urban/ rural
  - Mid-block/ intersection
- Divided or undivided
- Side barrier Y/N
- Road side object struck
  - Y/N
  - What was struck (categories)
- Other notable road and roadside factor mentioned in the TCR *(team to review)*

Other Data coding

- Infrastructure Risk Rating (IRR)
- Google Street View:
  - Helps comment on roads and roadside (i.e. edge lines, fog lines, road side barriers, centre median or barrier)
  - Sealed shoulder (A=0-200mm B=200-500mm C=500-1000mm D=1000-1500mm E= >1500 F= Unsealed road)

Road System Pillar Trigger (one or more):

- Struck non-frangible road-side object
- IRR- medium high or high
- Undivided 100km/h road and crossed the centre line
- Presence and size of sealed shoulder if relevant to the crash (A or B)
- Other notable road and roadside factors that aren't extreme *(team to review)*

Extraordinary road system factors:

Team to review: Other notable road and roadside factor mentioned in the TCR

User

TCR coding

- Age, gender
- Seatbelt worn Y/N/U
- Ejected Y/N
- Alcohol- reading/ suspected/ not suspected
- Fell asleep/ evidence of fatigue Y/N
- License type: learner driver/ restricted/ full/ overseas/ forbidden/ disqualified/ no license
- Crossed center line Y/N
- Unsafe overtaking (yellow, corner, oncoming vehicle) Y/N
- Left road to left Y/N
- Other notable behaviour (*team to review*)

User Pillar Trigger (one or more):

- Age >75
- No Seatbelt
- Ejected Y + U seatbelt
- Alcohol suspected
- Fell asleep
- Crossed centre line
- Left road to the left
- > 10km over limit
- License= learner/ restricted/ forbidden/ disqualified/ no license/ expired/ overseas
- "too fast for conditions"

Reckless behaviour:

- BAC over license conditions= reckless
- "suspected" alcohol= contributes
- Restricted or learner license + alcohol presence or "suspected"= reckless
- No license= reckless
- Attempted suicide or murder= reckless
- > 20km over speed limit= reckless
- > 10km over the speed limit= contributes
- Disqualified driver = contributes
- No seatbelt= contributes

Not reckless = lapses, errors, or mistakes

1.5. Results

In this section, we firstly present a summary of the findings from the literature scan. Following this, an overview of the results from the analysis is presented, followed by a more in-depth presentation of the results from the analysis.

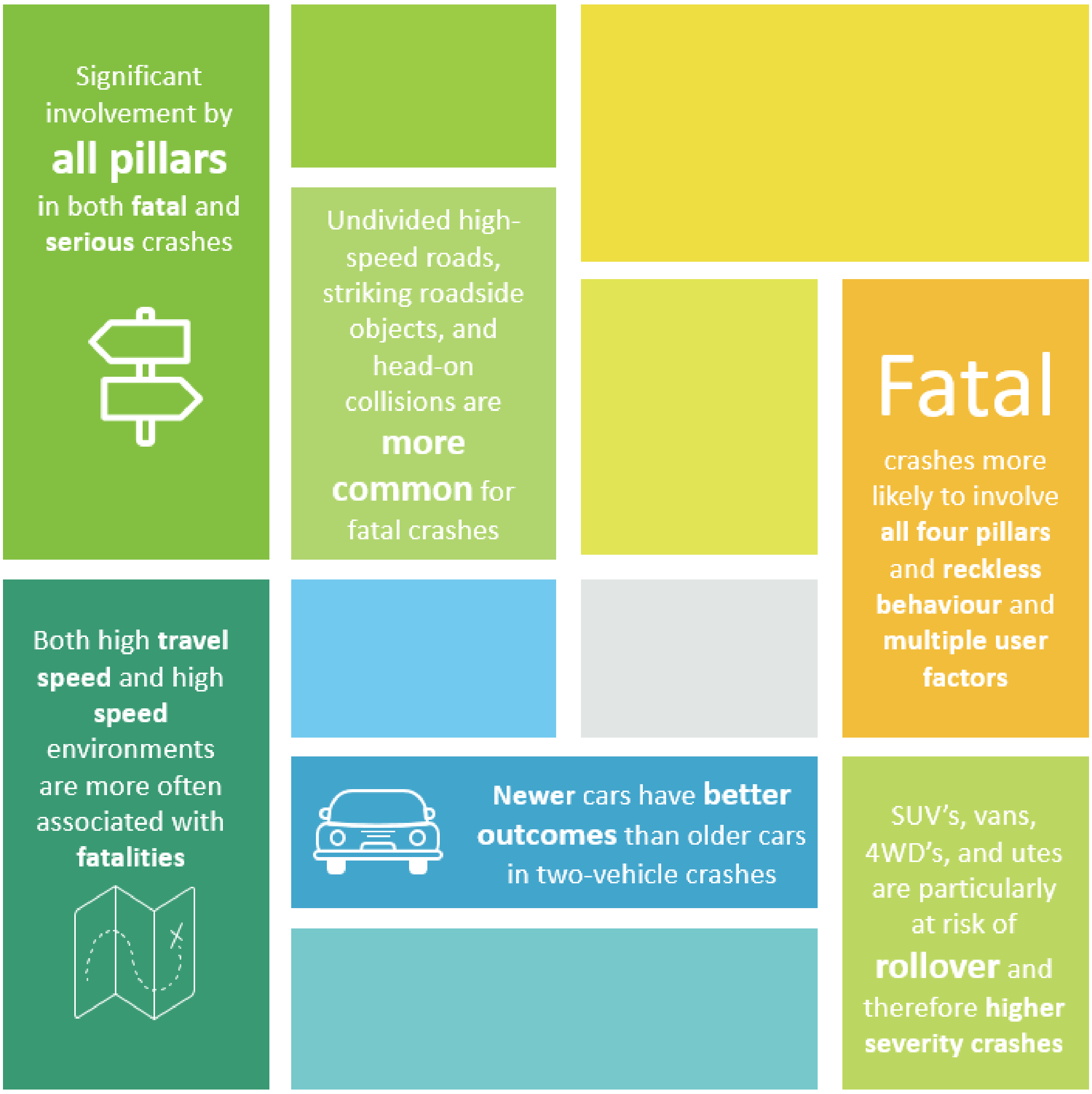
Key findings from the literature

Strong trends exist in the literature which indicate that particular risk factors are more likely to be associated with particular crash occurrences and outcomes. A detailed, fully referenced body of literature is presented in Appendix 1. However, some key factors include:

- Young inexperienced drivers are more likely to be involved in a crash;
- Although women are more likely to receive more serious injuries than males, males are more likely to be fatally injured in crashes;
- The behaviour of occupants in the vehicle has a strong influence on the outcome of a crash. In relation to poor crash outcomes, factors include seatbelt non-use, the presence of alcohol in the driver's bloodstream, high speeds, and other reckless driving behaviours;
- Vehicle occupants' survival chances are negatively associated with the vehicle's age;
- In single-vehicle crashes, SUV/4x4's are more likely than cars to roll, resulting in an increased injury risk; and
- Contact with road-side objects, such as trees or non-frangible poles are more highly associated with the probability of instant death.

Analysis Overview

A brief, visual quantitative summary from the CAS analysis is presented in this section. For more detailed results of the overview analysis relating to the conditions of all crashes, please refer to Appendix 2.



Involvement of system pillars in fatal versus serious crashes

One of the research questions was *Are there differences in the circumstances that lead to fatalities or serious injuries in New Zealand's light vehicle crashes?* To answer this, we have used a Safe System framework to examine the influence of each of the four safe system pillars on fatal and serious injury crashes. As described in the method in Figure 2, each pillar could be 'triggered', or implicated in a crash in response to certain factors being present. Interestingly, for the majority of both serious injury and fatal crashes, three to four Safe System pillars were activated, with the most common pillar relating to users (Figure 3), which is consistent with the often cited 90-95% of crashes resulting from human error (Dewar, Olson et al. 2007). However, focussing on users alone is unhelpful and the findings demonstrate that, in most cases, the cause and outcome of a crash are highly likely to be due to a combination of system factors.

Another interesting finding was that the speed and roads and roadside pillars were triggered more often for fatal crashes. This may reflect the destructive forces that are associated with higher speeds and associated collisions with roadside objects and other vehicles at 100km/h (due to no separation).

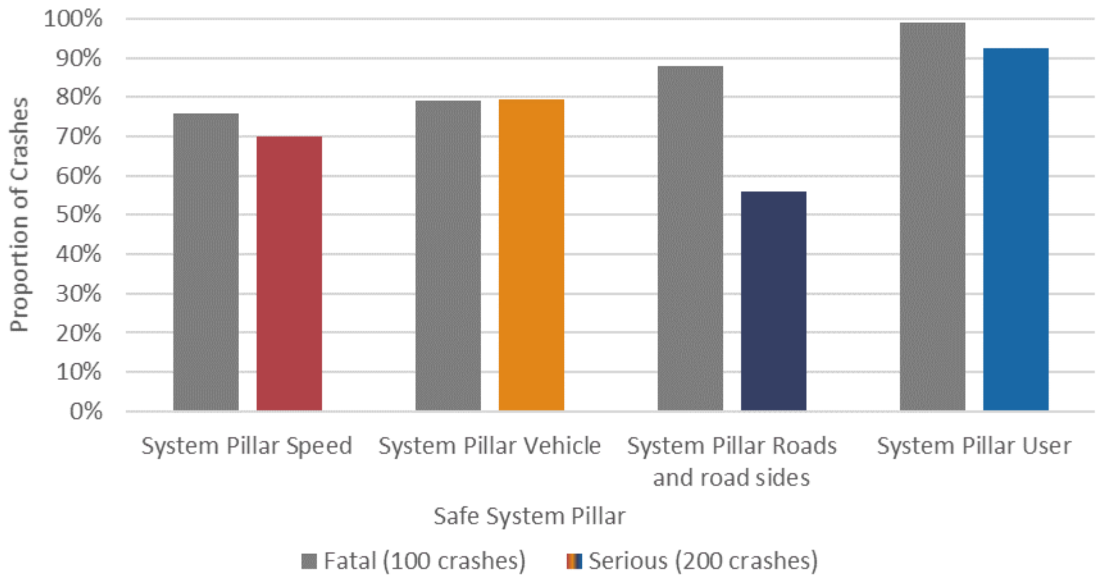


Figure 3: Proportion of fatal and serious crashes involving each System Pillar

The proportion of crashes (fatal and serious) where a combination of pillars were implicated is shown below in Figure 4. A key finding is that there are a significant number more fatal crashes where all four pillars of the Safe System have failed. This reflects contemporary accident theory (such as James Reason's Swiss Cheese Model (Reason 1990)), which holds that adverse events occur when multiple system failures allow it. Normally, at least one or more aspect of the system acts as a safety net to prevent a fatality from happening, even when errors are made. However, when all aspects of the system fail, then a fatality is clearly more likely.

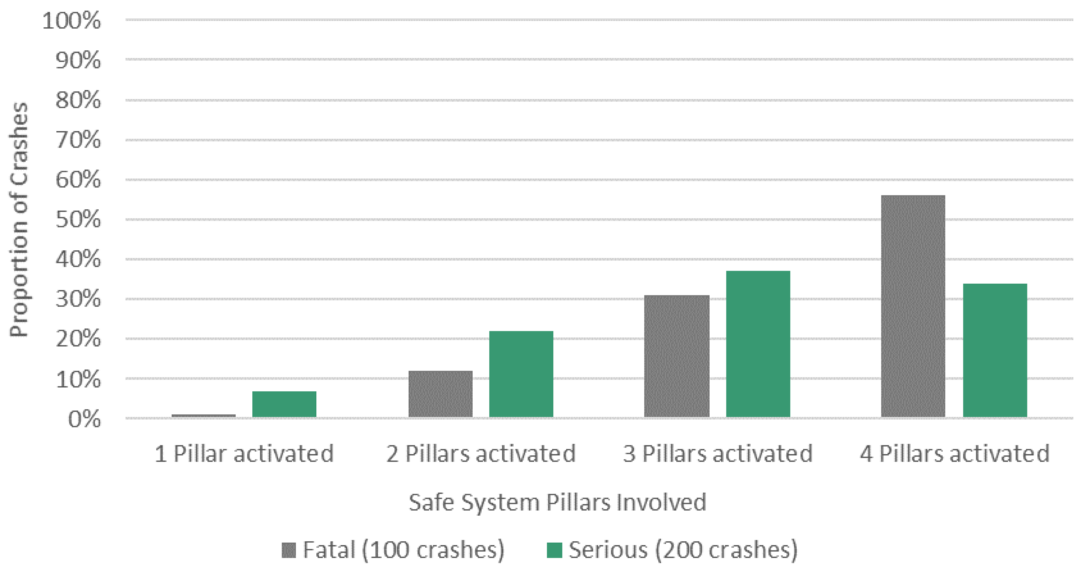


Figure 4: Proportion of fatal and serious crashes involving multiple System Pillars

The following sections present our findings based on factors within each pillar. Firstly, we discuss the components of the speed pillar in relation to the proportion of fatal and serious injury crashes. This is followed by a presentation of the vehicle pillar, followed by the roads and roadsides pillar, and finally the user pillar.

Speed Pillar

This pillar pertains to the speed environment as determined by the speed limit, advisory speed or whether the estimated travel speed or speed limit was greater than the Safe and Appropriate Speed as determined by the NZ Transport Agency Speed Management maps. It specifically relates to the set-up of the environment and the behaviour of an individual relative to that environment. Put simply, were they travelling too fast for the conditions and were speed limits appropriate? High travel speeds above the speed limit were treated as user factors.

Reckless behaviour was immediately triggered if speed was greater than 20km/h over the speed limit. 20% of fatal crashes and 7% of serious crashes met this criterion. Two examples of cars involved in fatal crashes were travelling at 178, and 173km/h. Other cars involved in fatal crashes had speeds of 150, 144, 137, 131 and 130 km/h. Crashes at these kinds of speeds, especially into fixed roadside objects like trees, poles, and bridge abutments are likely to be fatal even in modern vehicles.

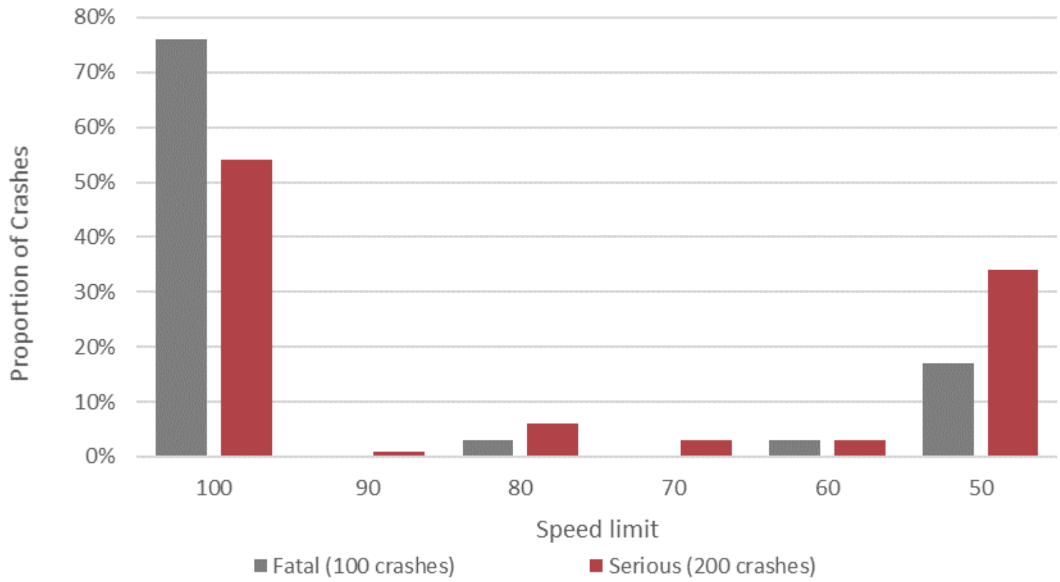


Figure 5: Speed limit at crash location

Speed is a key factor in the differences between fatal and serious crashes (Figure 5). Of the randomly selected fatal crashes 76% were in 100km/h environments whereas a much lower proportion (54%) of serious injury crashes were at 100km/h locations, with proportionately more serious injury crashes happening in urban environments. Accordingly, the opposite trend exists for 50km/h environments. This finding is not surprising and reflects the MOT Motor Vehicle Crashes in NZ data (Ministry of Transport 2016) which shows that 73% of fatal crashes are in open road environments and 40% of injury crashes are on urban roads. Collectively, these findings reinforce that the crash forces associated with travel speeds in 100km/h speed limits are less likely to be survivable.

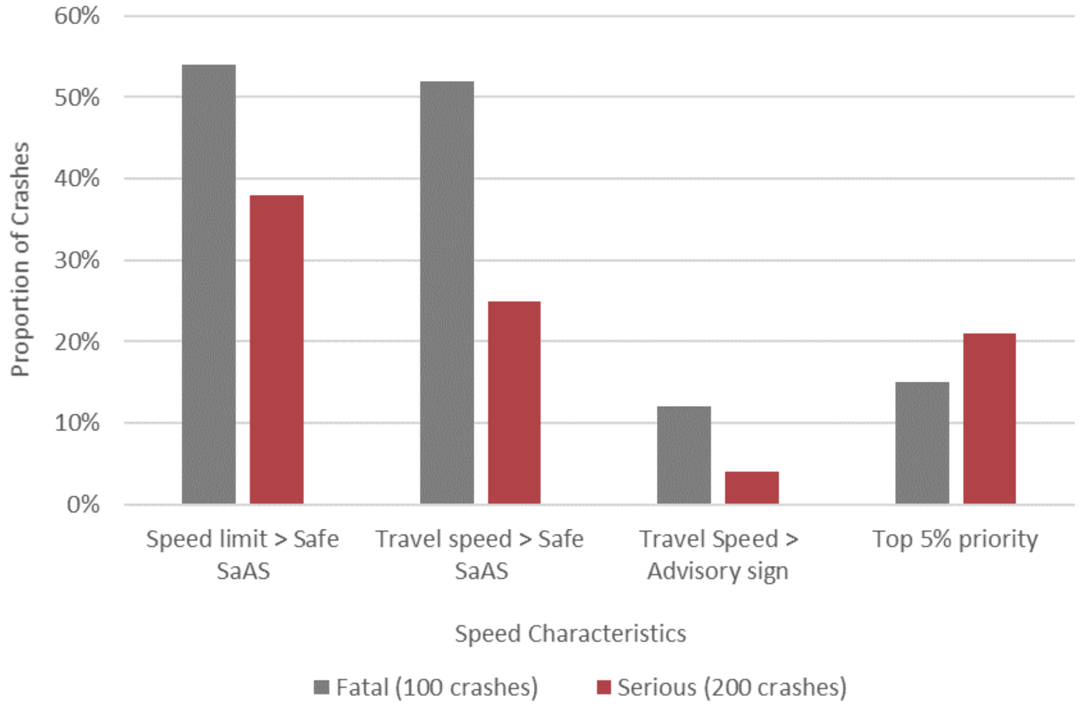


Figure 6: Speed Pillar

Vehicle Pillar

Vehicles that were 14 years or older triggered the vehicle pillar. The pillar was also triggered by the vehicle's Star Rating being between 1 and 3 (or not rated), a lack of side airbags (for side impacts), front airbags (for frontal impacts), or ABS, and other defects mentioned in the TCR (see Figure 7). Many of the older vehicles in the sample did not have ANCAP Star Ratings, so Used Car Safety Ratings (UCSR) were used if available. 26% (fatal) and 28% (serious) of crash vehicles were not rated for either UCSR or ANCAP on the Right Car website. The average age of the unrated vehicles was 20 years, so the star ratings of most unrated cars would be in the 1-2-star category. Some of the newer vehicles without safety ratings were from more obscure manufacturers with a relatively poor record in terms of vehicle safety.

Consistent with a significant proportion of the vehicles in the cohort being over 20 years old (Figure 8), the presence of airbags was highly variable and so it is not surprising that a greater proportion of fatalities involved vehicles without airbags. In 31% of the fatalities, where the information was available, these vehicles did not even have driver frontal airbags. This suggests that the vehicle contribution to safety should continue to reduce as the presence of airbags, ESC and other safety features will become more likely in crashes over time.

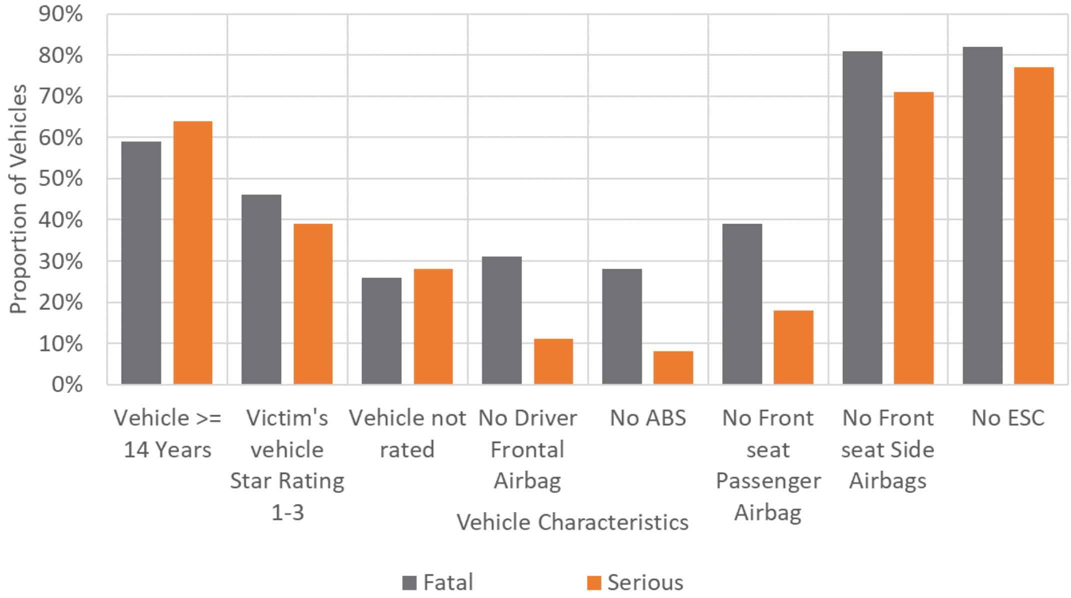


Figure 7: Vehicle age and safety features (when information available).

There are multiple considerations in understanding vehicles in crashes. Firstly, the average age of light passenger vehicles in New Zealand is 14.2 years (Ministry of Transport 2015, p.24). However, newer vehicles travel greater distances annually (Ministry of Transport 2015) and so, from an exposure point-of-view, the average age of vehicles on the road at any time (the average of age weighted by annual distance travelled) is likely to be lower than 14.2 years, although we cannot say exactly what this is from the present analysis. Nevertheless, the average age of the victims' vehicles in both fatal and serious injury crashes is significantly higher than the average age of vehicles on the road, meaning that older cars are over-represented in both fatal and serious injury crashes.

Secondly, for crashes involving another moving vehicle we see that for fatal crashes, the average age of the victims' vehicles is 16.0 years, while the average age of the other vehicle is 10.3 years. For serious injury crashes, the average age of the victims' vehicles is 15.5 years and the average age of the other vehicle is 11.0 years. In both cases the vehicles of the victims are significantly older than the other vehicles, again suggesting the protective effects of newer vehicles.

We might reasonably expect that the potential fatalities in the newer cars which instead became serious injuries would lower the average age of the serious injury victims' vehicles. However, there are about 10 times as many serious injury crashes as fatalities, and so any effect is likely to be swamped by the underlying level of serious injury crashes. Furthermore, some potential serious injury crashes in the newer cars will instead become minor injury crashes. This effect will tend to increase the average age of the serious injury victims' vehicles which will offset the effect on vehicle age of the fatalities becoming serious injuries.

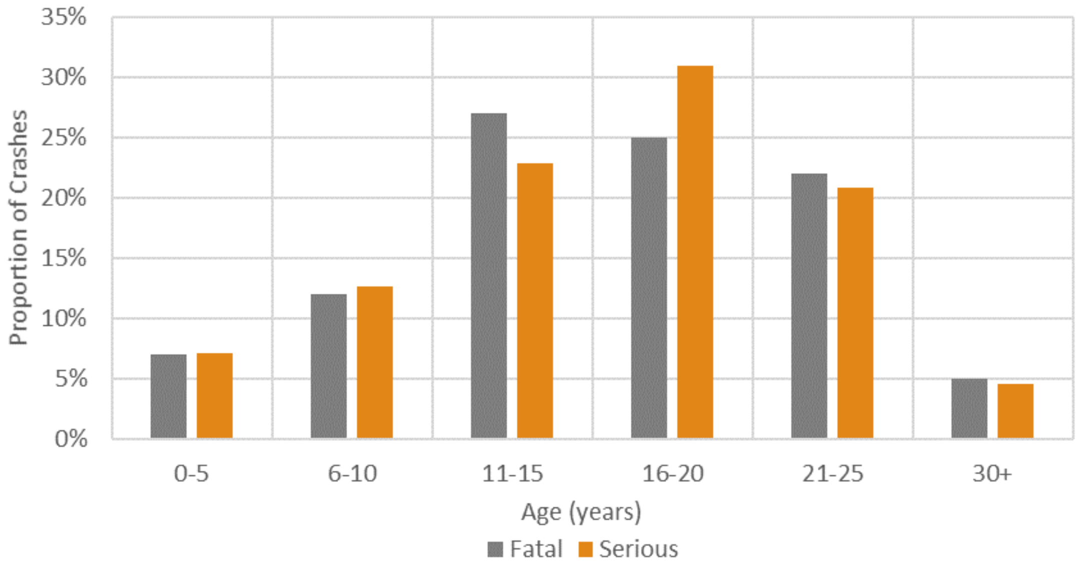


Figure 8: Vehicle age

New cars (5 years old or less) were involved in 7% of both fatal and serious crashes suggesting that although modern vehicles are generally safer, they still do not prevent fatal and serious injury outcomes if crash forces are sufficiently large. However, of more concern are the many older vehicles without any airbags, and SUVs/4x4s, and Utes without electronic stability control. Cars without passenger side airbags were also an issue and there were many examples of side impacts where the lack of a side airbag is likely to have been a contributing factor to a serious injury or death. This was particularly noticeable at urban intersections where many crashes resulted in serious injuries. This may have implications for some who feel that a cheaper/older car is sufficiently safe for use in urban areas, but, in fact, side protection as available in later model cars may be important in reducing outcome severity.

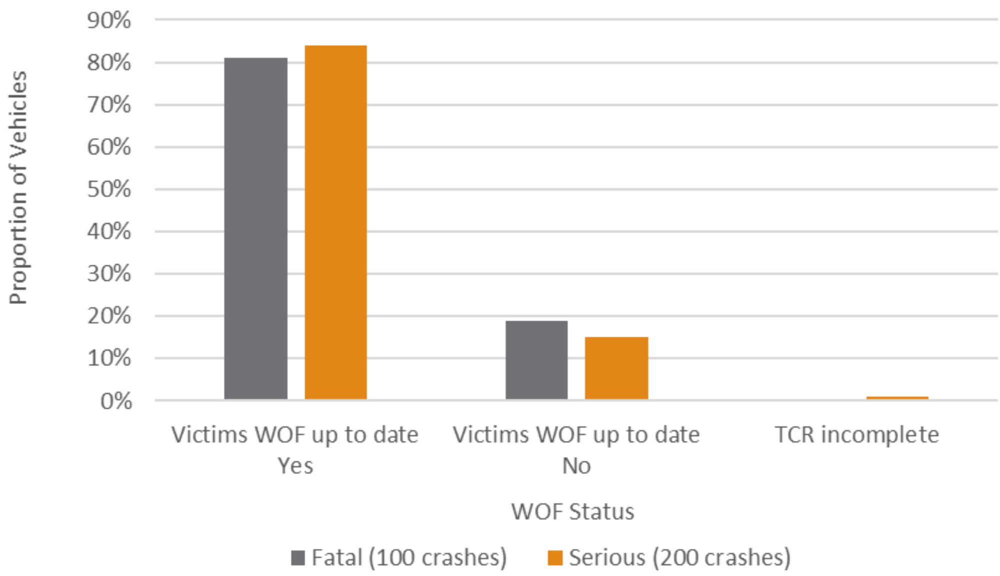


Figure 9: Warrant of Fitness current

Some vehicles were highly prone to roll over crashes with 54% of Utes and 38% of SUV/4x4 vehicles in the sample being involved in roll-over crashes, despite them accounting for approximately 8% and 9.5% of the sample respectively. As a comparison, only 14% of the cars in the sample rolled over and they accounted for 76% of the sample. The increased risk of roll-over by Utes and SUV/4x4 vehicles is shown in Figure 10. However, please note that only 7% of the fatal and serious crashes involved rollovers.

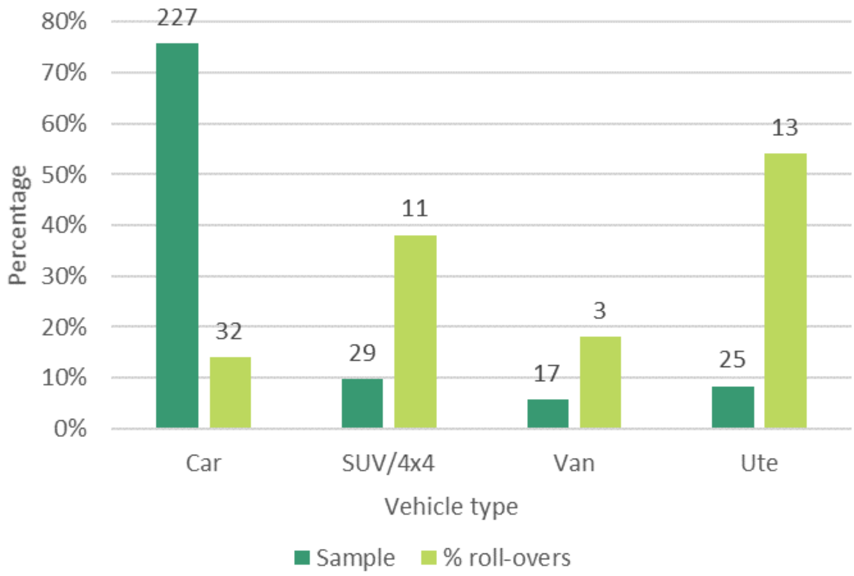


Figure 10: Vehicle type and roll-over crashes (absolute number of crashes given with columns)

Roads and Roadsides Pillar

Several factors contributed to involvement of the roads and roadsides pillar. Figure 11 below shows that 59% of fatalities were on undivided high-speed roads where the centreline was crossed (compared with 41% of serious injury crashes) and 55% of fatalities involved hitting a roadside object (compared with 31% of serious injury crashes). Interestingly, Infrastructure Risk Rating (from the Speed Management data) was not significantly different for fatal and serious crashes. It makes sense that a narrow shoulder coupled with leaving the road to the left was similar for fatal and serious crashes as this relates to the likelihood of a crash rather than the severity which is more likely to be affected by an object struck or not.

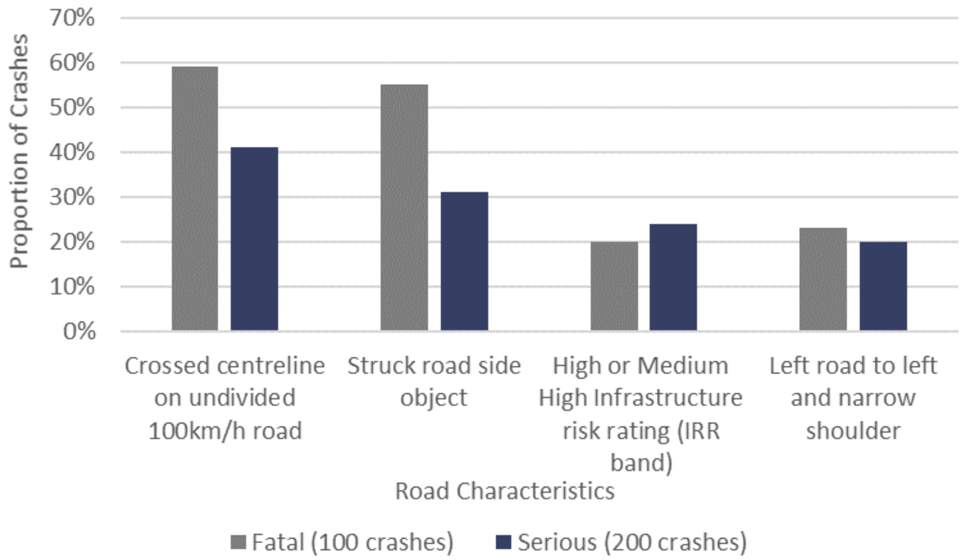


Figure 11: Roads and Roadsides Pillar

Other vehicles were the most frequent objects struck (Figure 12), followed by various roadside features. Serious Injury crashes more often involved hitting another vehicle, and this was more likely in urban environments where there is greater exposure to other vehicles and a greater frequency of intersections. Overall, the various objects struck reflect the lack of protection from these objects on the clear majority of New Zealand’s road network.

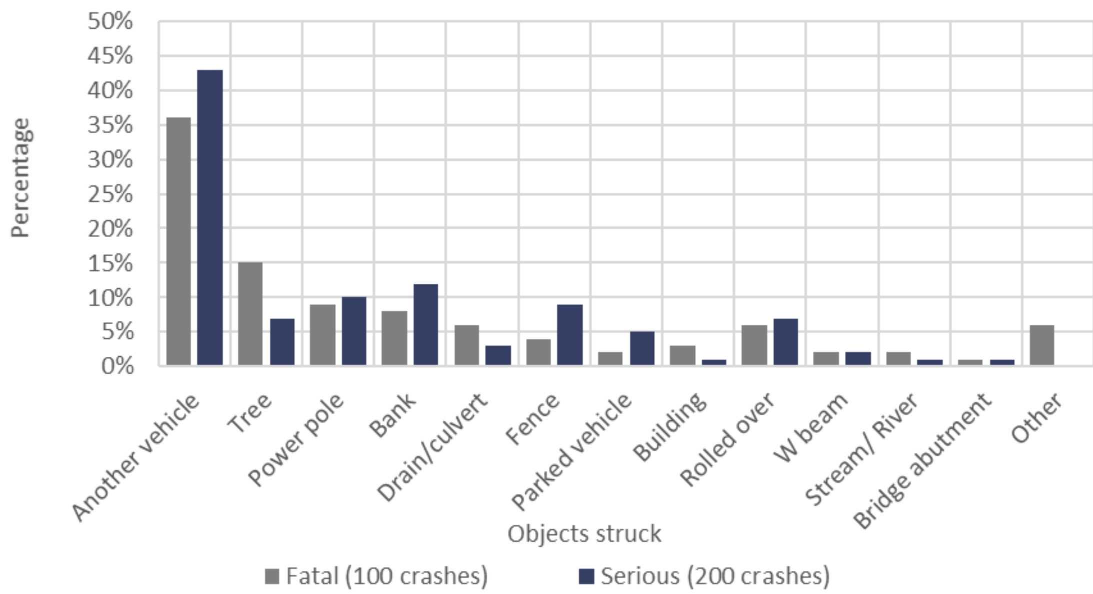


Figure 12: Objects struck

Of the 18 drivers that were killed after falling asleep, in seven of these instances, audio tactile line markings were in place. This is interesting as previous research has shown that ATP is an effective countermeasure for vehicles leaving the lane (Mackie 2009). However, it may be that if a driver is actually asleep as opposed to micro sleeping, or drowsy, the recovery reaction time is too great to prevent the vehicle from leaving the road, especially if shoulder width is minimal. Clearly barriers are more effective but also more expensive. Most fatal and serious crashes occurred on sections of the road without roadside barriers, with fatal crashes having roadside barriers less often (Figure 13).

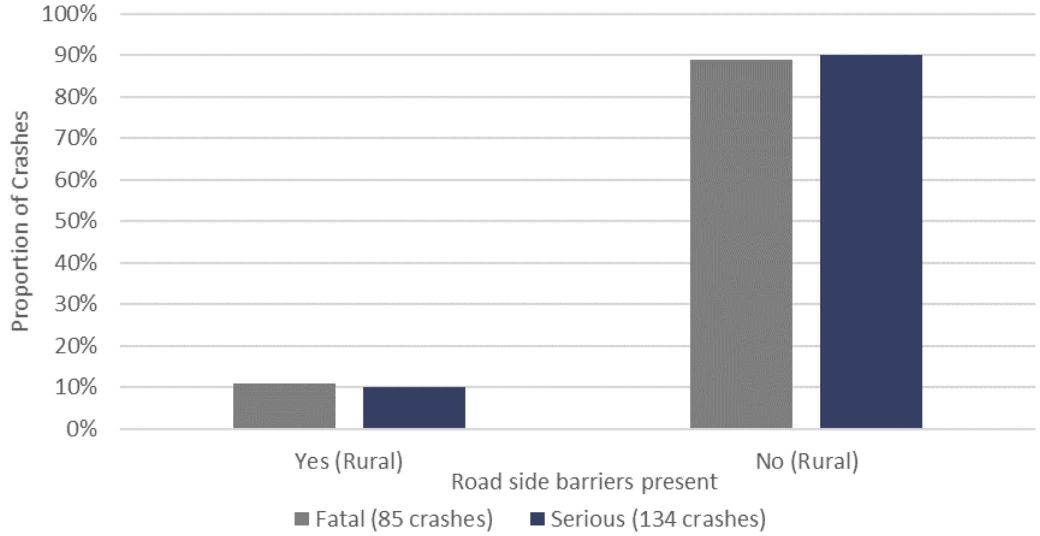


Figure 13: Presence of road-side barriers

The width of the sealed shoulders at the crash site was estimated using either images from Google Street View, or in rare examples given in TCR report diagrams. In total, 39% of fatal crashes involved vehicles leaving the road to the left. A lack of sealed shoulders or very narrow sealed shoulders leave little room for error. Wider shoulders also reduce the likelihood of striking road side objects.

Figure 14 shows that many fatal or serious crashes in rural areas happen when there is little sealed shoulder, which is not surprising as shoulder width is a recognised safety countermeasure and an important component of predictive risk rating tools such as KiwiRAP. While the proportion of fatal crashes is significantly more on shoulders greater than 1500mm, this is likely due to exposure.

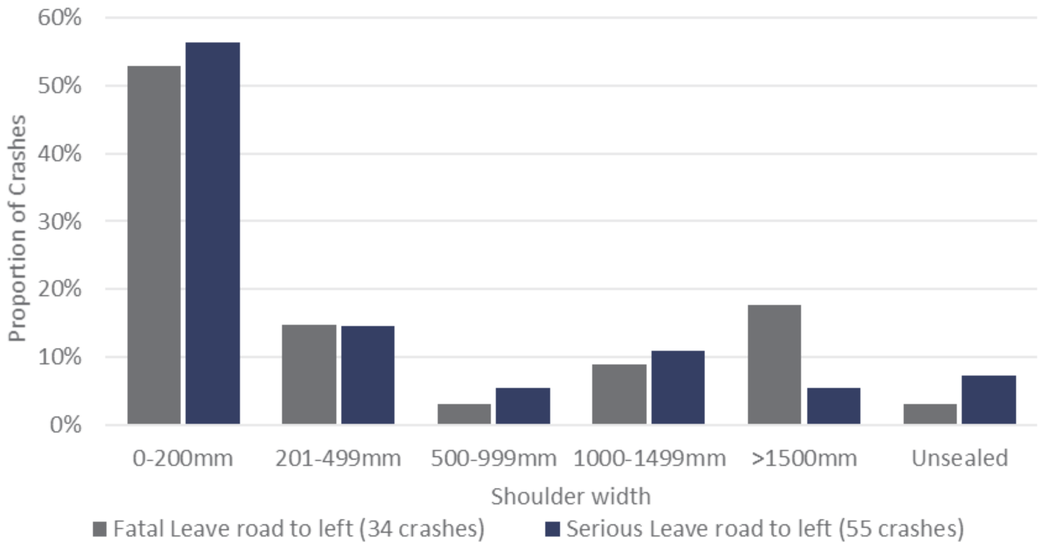


Figure 14: Leaving road to the left and shoulder width

User Pillar

The user pillar was implicated in 99% of the fatal crashes and 93% of the serious injury crashes. The graph below gives a breakdown of individual factors which were triggered in the user pillar. Please note that these categories are not mutually exclusive, for example most of those who were ejected were also not wearing a seatbelt.

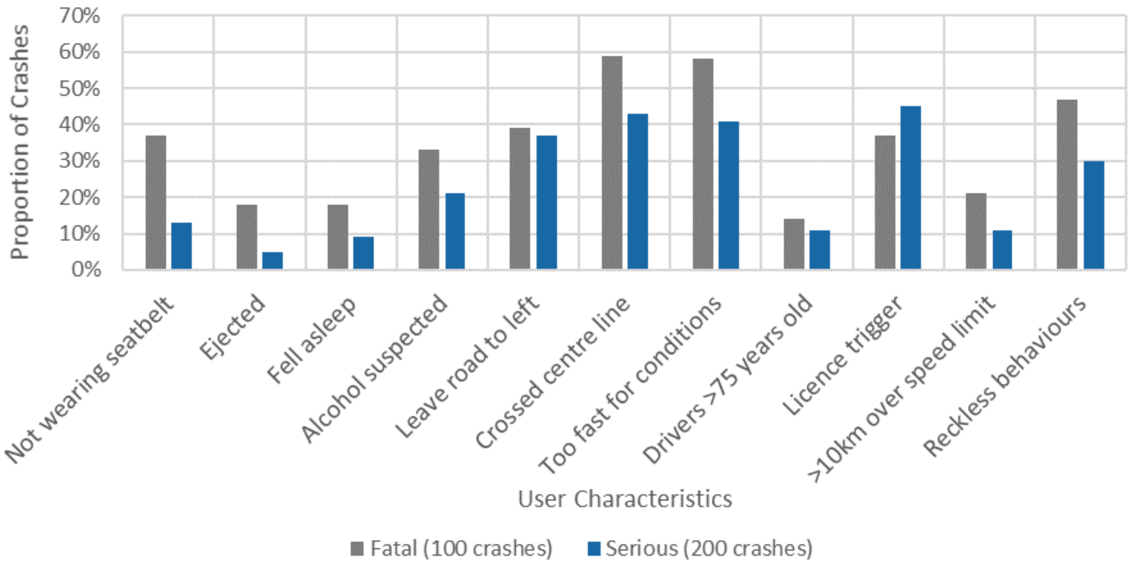


Figure 15: User Pillar trigger factors

We found that several factors often triggered the user pillar. For example, 54% of those not wearing seatbelts also either tested positive for alcohol or were suspected of alcohol impairment. Similarly, 26% of those not wearing seatbelts were also speeding (>20km/h over limit).

Proportionately, drivers not wearing a seatbelt were more likely to have a fatal outcome than a serious injury outcome and this is consistent with previous studies (e.g. de Pont 2016). There were two cases where the seatbelt was torn in the force of the crash; one case was due to high speed into a bridge abutment and in the other case the seatbelt may have been partially frayed and tore in the crash.

Drivers who crossed the centreline (60% fatal, 43% serious) and who were involved in head-on crashes were more likely to be killed than seriously injured (Figure 16). User errors such as falling asleep, misjudgements in overtaking or cornering, or loss of control were the most common factors leading to a driver crossing the centre line. This is an important consideration for roads and roadsides, particularly where 100km/h speed limits exist with no central barrier.

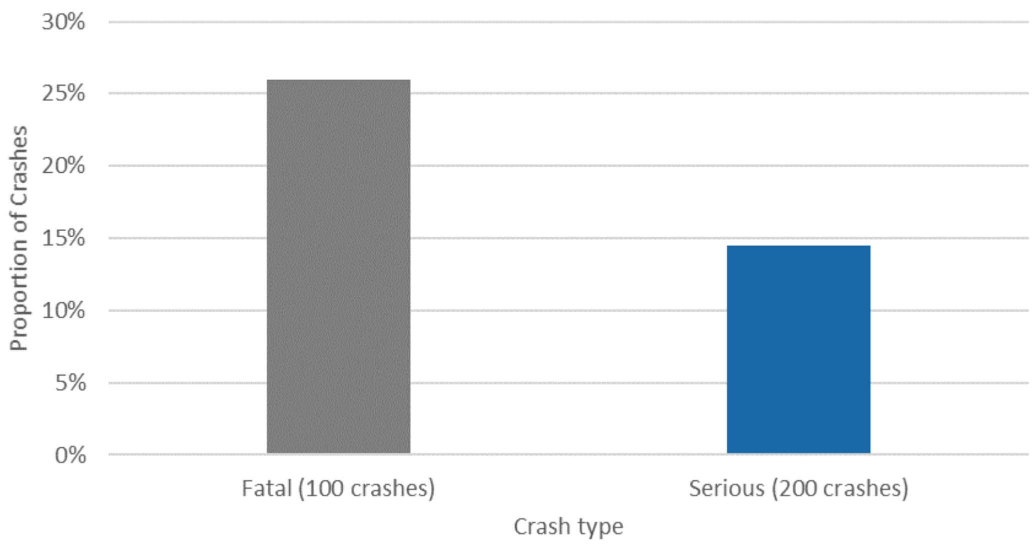


Figure 16: Head-on crashes

Drivers in fatal and serious crashes held similar licenses (Figure 17) with a slightly greater proportion of full license holders in the fatal crash cohort. This may reflect the greater number of urban serious injury crashes where a greater mix of license holders are more likely, rather than the skills and competence of people on different licence types.

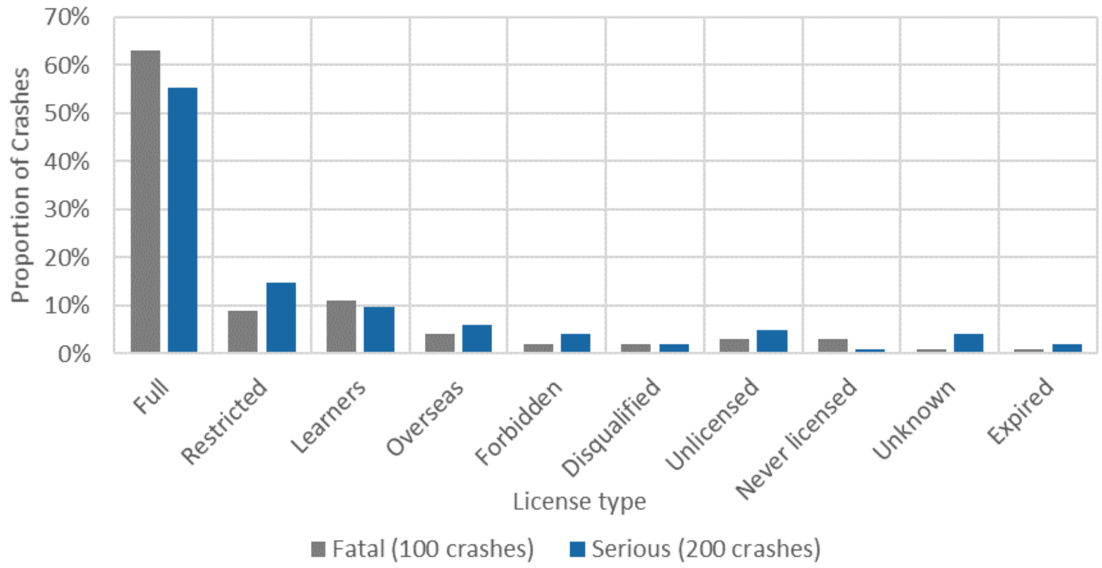


Figure 17: License type for fatal and serious crashes

With regards to people crashing with a Restricted licence, 16.6% (6/36) were alcohol involved. Two further individuals were suspected, but no alcohol reading was recorded. In addition, three people were in breach of their licence conditions due to driving between 10pm and 5am. It is unclear how many of these drivers were in breach of their licence conditions due to passenger ages as this information was not presented in the TCR. With regards to Learner's licences, 41% (12/29) were alcohol involved. Interestingly, the age range for these drivers was between 18-44 years, with most people in their late 20s. It is possible that some of these licence holders may be recidivist drivers who had previously lost their licence. However, with no detail provided in the TCRs to support this case, this is speculatory.

Involvement of 'reckless' behaviour

A second question for this part of the research was:

What proportion of crashes result predominantly from system factors as opposed to reckless behaviours?

As mentioned in the review of literature, this question was addressed by (Wundersitz and Baldock 2011, Wundersitz, Baldock et al. 2014). Therefore, to some extent we can compare the outcomes of this analysis with the findings of this previous Australian study. However, there are significant differences in the studies and care is needed in making direct comparisons.

Figure 18 below shows the proportion of fatal and serious crashes that resulted from 'system failure' compared with crashes where reckless behaviour was clearly evident. Interpretation of this distinction is very important as even where reckless behaviour is evident, in many cases the system should be designed in a way that prevents death or serious injury. However, if a person chooses to travel at 170 km/h then in such an extreme example, it is much less likely to be survivable and it is probably unrealistic to expect that the roads, roadside, and vehicle aspects of the system will be able to provide a safety net. Nevertheless, under a Safe System approach to road safety, further questions could be asked about why a person chooses to travel at 170 km/h. At a basic level this analysis shows the extent to which road users have contributed to the fatal or serious crash. Taking a different view, vehicle systems could easily be implemented to prevent this speed occurring, but political acceptability is another matter.

For fatal crashes, using the criteria for reckless behaviour as explained in Figure 2 earlier in the method section, approximately half of the crashes resulted from reckless behaviour. This contrasts with serious crashes where 29% of crashes were categorised as including reckless behaviour.

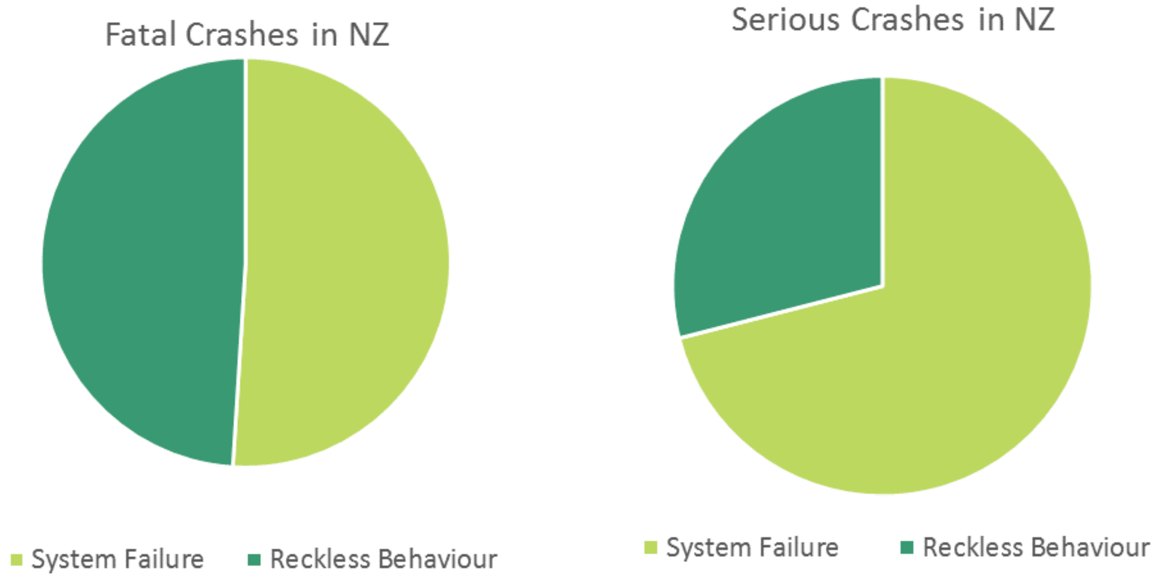


Figure 18: System failures and reckless behaviours in fatal and serious crashes NZ

This suggests that, despite the differences in study design, fatal crashes more often are the result of reckless behaviour and this is similar to the overall findings of Wundersitz and Baldock (2011), as shown in Figure 19. However, both studies also show that across fatal and serious crashes, more often crashes do not involve reckless behaviour. Furthermore, earlier in the report, we showed that fatal crashes were more likely to have all four pillars of the safe system implicated. Therefore, even when reckless behaviour is involved, there is still a need to understand the contributions from all parts of the system, to a person's death.

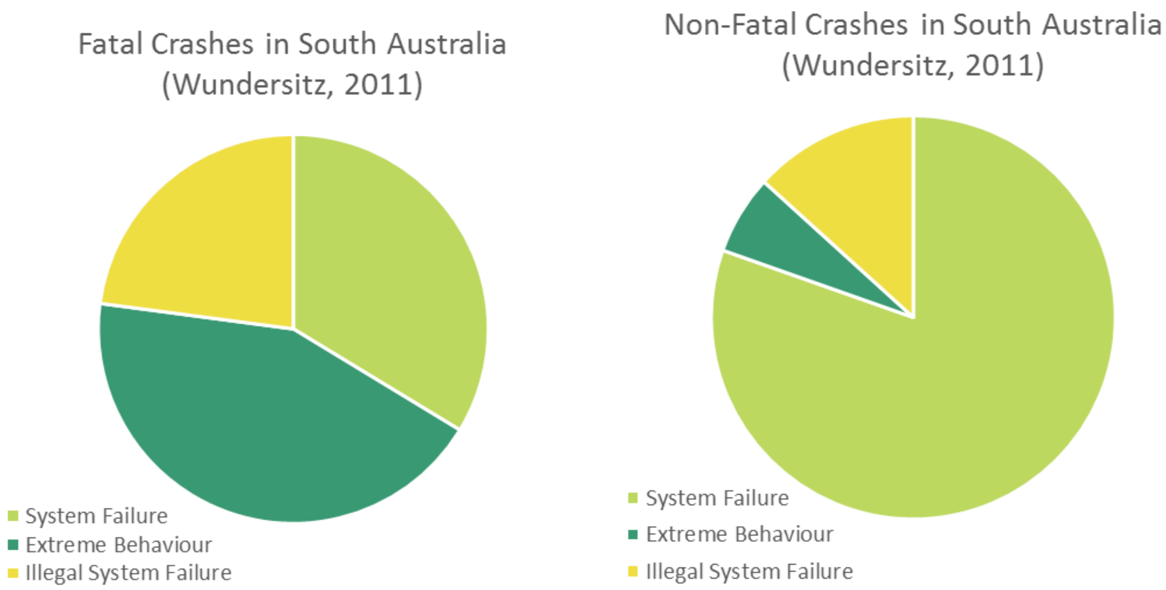


Figure 19: System failures, illegal system failures, and extreme behaviours (Wundersitz and Baldock 2011)

Another useful comparison is with the now somewhat dated High Risk Driver statistics presented by the Ministry of Transport (Ministry of Transport 2012). Between 2006 and 2010 it was found that 34% of at fault drivers in fatal crashes were 'high risk' and 22% of serious injury crashes were 'high risk' – using a slightly more 'extreme' set of criteria than that used in this study. For example, the alcohol criteria for our definition of 'reckless' was anything over the BAC limit for a given license type, whereas the MOT criteria for high risk drivers at least fifty percent over the adult legal limit.

This comparison raises an interesting question about what 'reckless' or 'high risk' means. The previous MOT statistics for High Risk Drivers include traffic offence history and are clearly intended to identify those who are recidivist offenders. This is different to the Safe System focus of this report which instead focuses on the relative contribution a driver made to the likelihood and consequences of crashes in which they were involved. It therefore makes sense that the present analysis has a relatively higher proportion of reckless behaviour for fatal crashes than the proportion of High Risk Drivers identified in the earlier MOT statistics, and the present analysis focusses more on everyday behaviours that are operating outside of the legal and 'safe' boundaries determined by the system.

1.6. Discussion

A key finding from this analysis is that crashes often happen because of multiple system failures and this further supports the importance of the Safe System approach in road safety. Given that a large proportion of fatal crashes exhibited failures by all pillars of the safe system, road safety efforts should be rigorous in addressing all four pillars.

Various models of human behaviour, public health, and road safety suggest that the surrounding environment is the greatest determinant of health or safety outcomes. It makes sense therefore that significant effort is given to addressing the roads and roadsides pillar by introducing side and median barriers, rural roundabouts, and other safe system treatments on high speed roads. However, it may be difficult to effect change in the other pillars and so progress is slower. In addition, it seems unrealistic that the entire road network of New Zealand will receive Safe System treatments in the foreseeable decades given the cost implications, and so other Safe System pillars that will help provide the safety net to prevent fatal and very serious crashes also need to be considered. For a long time, other than road design improvements vehicle advances have been the main area of progress, but the speed and user pillars may need to play a bigger role.

Often, it was clear in the analysis that minor driver lapses resulted in serious or fatal outcomes. This contrasts with the Safe System approach which explains that although people make mistakes, the consequences for those mistakes should be mitigated by safe roads and roadsides. For example, 13 fatal and 14 serious injury cases in this study were initially due to a vehicle leaving the road to the left, but the loss of control on the unsealed shoulder then caused the vehicle to cross the centre line. Crossing the centre line with the result of a head-on crash is an example of the interaction between two Safe Systems Pillars, in this instance, the ‘User’ pillar and the ‘Roads and roadsides’ pillar. The travel speed may also have influenced the likelihood of this error and would certainly affect the injury outcome.

The analysis also showed that a high proportion of fatal crashes involved reckless behaviours with often multiple ‘unsafe acts’ being committed. It seems unlikely that conventional approaches to road safety will effectively address these situations and more work might be needed to identify these risky individuals or situations, taking a multi-agency approach. Other agencies, involved, for example, in domestic violence have experience in identifying high-risk situations and developing action plans for them. Extreme traffic behaviour may be just one symptom of a socially dysfunctional context and therefore the transport system alone may not be effective in addressing these highly reckless behaviours. Different to very risky individuals, are the many motorists who may be more conventional in their lifestyle but still exhibit one or two reckless behaviours through their driving. For this population sub-group, continued effort to influence driving norms is needed.

For speed, the analysis clearly shows the implications of speed on crash severity risk. Conceptually, it is already well known that speed is a strong determinant of death or serious injury, and this analysis demonstrates in a very real way the effects of speed on the most recent fatal and serious crashes. This means that initiatives such as the government’s Speed Management Programme are likely to be very important in the future.

There are a multitude of factors that can affect the outcome of a crash, and with this cohort of already older than average vehicles, a range of factors can influence the fatal or serious injury outcome. When the same conditions are applied (e.g. two vehicle crashes), we found that the occupants of newer vehicles were associated with lower severity outcomes. However, new vehicles (0-5 years old) were not immune from either fatalities or serious injuries and thus a new vehicle is not sufficient in itself to remain safe on New Zealand’s roads in all circumstances. Death is still a possibility when crash forces reach certain levels, and so again, other pillars of the Safe System also need to work effectively.

There are a number of limitations with this research. The analysis is limited by the information available in TCR reports and associated speed management and vehicle safety databases. It does not provide a depth of understanding of individual crashes that might be achieved from Serious Crash Unit reports. Nevertheless, we did find that for most crash cases, the information available provided a reasonable understanding of the system pillars that were likely to have played a part in the crash. The uncertainty was more related to the extent to which each pillar was critical in the crash. Also, the scope of work was deliberately limited to light vehicle crashes, so that with the limited sample, a reasonable comparison of fatal and serious injury crashes could be made. Further work could be carried out for other road-user groups as needed.

PART 2
UNDERSTANDING SERIOUS MOTOR VEHICLE TRAFFIC CRASH INJURIES

2.1 Introduction

For Part 2 the goal was to develop a profile of road crash injuries to better understand the proportion and nature of serious injuries that could be considered life-altering trauma, compared with less-extreme injuries like a broken bone. To achieve this goal, this section provides a description and comparison of serious and less serious motor vehicle traffic crash injuries as recorded in two separate data sets: The National Minimum Data Set of hospital discharges (NMDS) and the Auckland Hospital's Trauma Registry (AHTR). The following provides a brief overview of the data sources for this analysis.

- NMDS (Ministry of Health 2015): The National Minimum Dataset (NMDS) is a national collection of public and private hospital discharge information, including coded clinical data for inpatients and day patients. The NMDS is used for policy formation, performance monitoring, research, and review. It provides statistical information, reports, and analyses about the trends in the delivery of hospital inpatient and day-patient health services both nationally and on a provider basis. It is also used for funding purposes.
- AHTR: Auckland City Hospital is New Zealand's largest public hospital. In addition to comprehensive in-patient care for patients with a wide range of injuries, it serves as a tertiary referral service for the care of the severely injured in the region. Approximately 15-20% of trauma admissions to the hospital have an Injury Severity Score (Injury Severity Scale) > 15.[1] Auckland City Hospital receives some patients directly from the scene and others following transfer from other hospitals. Incorporated within a system design, the 'trauma team' provides immediate skilled emergency care for trauma patients in the Department of Emergency Medicine. Criteria for a call to the Trauma Team are outlined in Appendix 3.

Determining "seriousness" of injuries

There is no one standard definition of 'serious injury' and the concept is debated on several grounds. While it is widely recognised that injuries of lesser severity can impose significant longer-term physical, psychological, and social consequences, most commonly used indicators or descriptions of serious injury reflect the probability of a threat to life.

The definition of a Serious Injury in the New Zealand Transport Agency's Crash Analysis System (CAS) is (Stats NZ 2017):

> *Injury (fracture, concussion, severe cuts or other injury) requiring medical treatment or removal to and retention in hospital.*

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[1] Although an ISS score greater than 15 is conceptualised as "major trauma" in academic literature, the clinical identification of major trauma is more complex. For a full definition of Major Trauma, see National Major Trauma Clinical Network (2017). New Zealand out-of-hospital majot trauma triage policy, Major Trauma National Clinical Network, St John, Wellington Free Ambulance.

The ways in which the healthcare system, especially hospitals, consider injury seriousness are much more detailed, acknowledging the complexities in the nature of the injuries sustained and the likelihood of clinical outcomes, especially death.

The capture of an injury event within hospital discharge database or trauma registry data implies a level of severity – that the injured person was not able to walk away from the event without concern about their on-going health and wellbeing. However, decisions whether to accept an injured person for admission to hospital (and therefore potential inclusion in a discharge database or trauma registry) may vary by hospital admission policies, the availability of alternate treatment options (for example, fracture clinics) as well as the capacity of the treatment centre to respond to the need at the time of presentation. To reduce the impact of these extraneous factors, and allow monitoring of injury incidence in a robust manner, the *Serious Injury Outcome Indicators* (Serious Injury Outcome Indicator) are published by Statistics New Zealand on an annual basis using the NMDS. To be eligible for inclusion in the *Indicators* requires that the injury event resulted in a threat to life of 6.9% or higher as determined by diagnostic specific survival probabilities (see Appendix 4 for a description of the calculation of threat to life). While this provides greater assurance that all injuries deemed 'serious' and captured in the Serious Injury Outcome Indicator reports are very likely to have an adverse outcome, trauma care specialists consider a threat to life of 6.9% to be considerably higher than their threshold for considering an injury serious.

Injury severity can also be captured through the use of other methodologies, such as the Association for the Advancement of Automotive Medicine's Injury Severity Score (ISS). The Injury Severity Scale is derived from the Abbreviated Injury Scale score for the three most severely injured body regions (see Appendix 5 for a description of the calculation of Abbreviated Injury Scale scores and calculation of the Injury Severity Scale). Injury Severity Scale scores of greater than 15 are considered (in combination with other clinical indicators) as major trauma (National Major Trauma Clinical Network 2017). Although it is possible to calculate Injury Severity Scale from the information contained within the NMDS, mapping programmes are required to do so, and this process may introduce errors (or a level of misclassification). In contrast, the AHTR captures data on how severe an injury is as categorised by trained coders using Abbreviated Injury Scale scores for separate body regions based on information recorded by clinicians. The AHTR translates the scores from all body regions using a computerised formula to provide an overall Injury Severity Score (ISS) for each injury admission. The Injury Severity Scale (Baker and O'Neill 1976) is an indicator of threat to life (in other words, a higher score implies a greater likelihood of dying from the injury).

In addition, the AHTR captures Glasgow Coma Scale (Glasgow Coma Scale) scores as recorded at the scene of the injury and at admission to the Emergency Department. First introduced in 1974 and used in adapted forms since, a Glasgow Coma Scale score (Teasdale and Jennett 1974) provides a way of recording the state of consciousness of a person (see Appendix 6), providing a brain specific estimate of injury severity. "Severe" brain injury is indicated when Glasgow Coma Scale scores are less than 9.

Each of the above seriousness indicators have advantages and disadvantages that have been the subject of a number of academic articles (Brenneman, Boulanger et al. 1998). There are, however, other methods of understanding "seriousness", including on-going disability (Derrett, Langley et al. 2009) and the psychological impact (Holsinger, Steffens et al. 2002) of the injury event. Such measures of seriousness require long-term follow-up of the injured patient. In contrast to indicators of threat to life (e.g., Injury Severity Scale), reliable indicators of long-term disability remain elusive.

The aim of this investigation is to provide a baseline understanding of the distinguishing features of serious and less serious motor vehicle traffic crash injuries, defined in terms of threat to life. It is envisaged that this will provide a more fine-grained analysis of the crashes that would normally be categorised as "serious" using the CAS definition. Acknowledging some variations in the definitions (noted earlier), information on "seriousness" is drawn from both the NMDS and the AHTR, with analyses focusing on the *Serious Injury Outcome Indicators*, Injury Severity Scale and the Glasgow Coma Scale.

A note on Trauma Registries

While the Auckland Hospital Regional Trauma registry data has been used as an example of the information that can be drawn from a Trauma registry, it should be noted that this registry does not cover the New Zealand population as a whole. Instead, the information that can be derived from it is relevant to motor vehicle crashes that occur in the Auckland region, or that are transferred to the AHTR from other hospitals (for example, from Northland hospital). The Major Trauma National Clinical Network (MTNCN) was established in 2012 to address concerns about "the possible high mortality rate and variation of care for trauma patients in New Zealand" (New Zealand Major Trauma Registry & National Clinical Network 2016, p.3). The goal of the network is to establish a contemporary trauma system across the whole of New Zealand. It is envisaged that some of the benefits of this network will be reductions in mortality, improvements in long-term disability outcomes and cost saving. Alongside regional trauma registries, the Major Trauma Registry has been established to allow reporting of the incidence of major trauma at the national level. The coverage of DHBs across the country to this data set and it is expected that the potential of a nation-wide trauma registry will be realised within the near future. In the interim, the present analysis uses data from the Auckland City Hospital Trauma Registry (AHTR) to examine the research questions.

A note on the terms used

As highlighted above, three separate thresholds for determining "seriousness" have been included in this section. However, all of the cases included for analysis in this section have been admitted to hospital and are included in the NZ Police definition of a serious injury motor vehicle traffic crash. Approximately 15% of injury-related hospital admissions are captured using the *Serious Injury Outcome Indictors* threshold (Statistics New Zealand 2011). Further, 15-20% of all Trauma patients have an Injury Severity Scale score > 15 (New Zealand Major Trauma Registry & National Clinical Network 2016). It is our contention that all injury events that are admitted to hospital should be considered serious, but the degrees of seriousness can be categorised further. As the thresholds used in this document are measures of threat-to-life, we have chosen to use the following terms to classify injury events that meet the three seriousness thresholds:

- Serious Injury Outcome Indicator (Serious injury outcome indicators) high threat to life (>6.9% likelihood of death);
- Serious Injury Outcome Indicator (Serious injury outcome indicators) low threat to life (<6.9% likelihood of death);
- Injury Severity Scale (Injury Severity Score) high threat to life (>15);
- Injury Severity Scale (Injury Severity Score) low threat to life (<15);
- Glasgow Coma Scale (Glasgow Coma Scale) high threat to life (<9);
- Glasgow Coma Scale (Glasgow Coma Scale) low threat to life (>9).

Throughout this section the term "Motor Vehicle Traffic Crash" (MVTC) injury events is used as a grouping variable to capture the injury events described. A *Traffic Accident* is described by the International Classification of Diseases and Health Related Conditions (Version 10) (National Centre for Classification in Health 2002, p.451) as:

> *Any vehicle accident occurring on a public highway [i.e. originating on, terminating on, or involving a vehicle partially on the highway]. A vehicle accident is assumed to have occurred on a public highway unless another place is*

specified, except in the case of accidents involving off-road motor vehicles, which are classified as non-traffic accidents unless the contrary is stated

"Pedestrians" and "Cyclists" are included in MVTC injury events where they are coded as traffic accidents in the NMDS. It is important to note that pedestrian or cycling injuries not captured in the definition noted above (e.g., injuries sustained in footpaths, driveways, and off-road) are excluded from the analyses presented.

2.2 Method

Using the Serious Injury Outcome Indicators methodology, developed by Professors Colin Cryer, John Langley, and colleagues in New Zealand, we identified injury events that are considered a high threat to life ($\geq$6.9% chance of death upon admission to hospital). The set of motor vehicle crash-related injury cases identified using this approach would be widely acknowledged as serious, and would almost always be admitted to hospital, unless resulting in a death prior to hospitalisation.

Detailed analyses of NMDS data over 10 years were carried out to identify the different types of injuries experienced by road crash victims that come within the scope of 'serious injury' as determined by the methodology above. This provided a profile of road crash injuries that will increase our understanding about the numbers and frequencies of injuries (presented as absolute numbers as well as population-based rates) that can be considered significant threats to life, as opposed to less severe injuries that would still normally be classed as serious injuries by CAS (injury, fracture, concussion, severe cuts, or other injury requiring medical treatment or removal to and retention in hospital). The analysis also examined the types of injuries that contribute to these life-threatening events.

The analysis was complemented with a more detailed review of the motor vehicle-crash related admissions captured by the AHTR which has specific codes and classifications that can provide a greater appreciation of the specific injury types that pose threats to life. Using these two sources of data (NMDS and AHRT), an appreciation of the relative proportions and characteristics of injuries that result in a high threat to life and low threat to life was achieved.

Several different measures are presented in the results section. Definitions for each of these measures are provided below:

Frequency: The number of events that have occurred.

Rates: The number of events adjusted for the number of people at risk. In this report, the number of people at risk is the population of New Zealand. As the numbers of people at risk (i.e., the population base) increase, the numbers of events can be expected to increase. Adjusting for the number of people at risk answers the question: "If the number of people at risk stayed the same, would there be any change in the number of events?" Rates are calculated using the following formula:

$$\text{Rate} = \frac{\text{Frequency}}{\text{Population at risk}} * 100{,}000$$

Expressed as "rate per 100,000 population"

Age standardised rates: Age standardisation is a process by which differences in the age distributions of populations are considered when calculating rates. Adjusting for age ensures that differences in an outcome that has a strong association with age (such as fatal motor vehicle traffic crashes) are not merely reflecting the changes in the age structure of the population (such as population aging).

2.3 Results

"Serious injury" is *not well defined*

Common indicators focus on **threat to life**, but less severe injuries can impose **long-term physical and psychological disability**

People >45 years increasingly experience high threat to life injuries. Particularly **motorcycle riders** and **cyclists**

59%
major trauma cases
were **severe or critical**
head, neck, or cervical spine injuries

These trends **require attention** within a *comprehensive transport system approach*

Car occupants account for **60%** high threat to life non-fatal motor vehicle injuries

37% thorax injuries were **severe or critical**

Future work could examine a more detailed investigation of non-traffic crash injuries involving pedestrians and cyclists

Overall

As highlighted above, the definition of a serious injury in the New Zealand Transport Agency's Crash Analysis System is:

> *Injury (fracture, concussion, severe cuts or other injury) requiring medical treatment or removal to and retention in hospital.*

The number of injuries that receive medical attention, but which are not transported to hospital are difficult to enumerate, and so have not been considered within this report. Between 2007 and 2015, on average, there were 8,741 injury hospitalisations resulting from a motor vehicle traffic crash in New Zealand, fulfilling the Crash Analysis System's definition of a serious injury. Of these, an average of 1,539 (18%) were considered high threat to life by the serious injury outcome indicators. Therefore, around 80% of injuries considered serious by the Crash Analysis System would not be considered high threat to life under Statistics New Zealand's Serious Injury Outcome Indicators.

Further detail concerning the differences between high and low threat to life injuries for different ages, road user groups, and using different definitions of threat to life are provided below. Overall, compared with low threat to life injuries, high threat to life injuries are characterised by serious head injury (including subdural haemorrhage,[2] or a subarachnoid haemorrhage[3]) and / or a number of different injury diagnoses. Twenty percent of high threat to life injuries treated at the Auckland Hospital Trauma Service sustained 10 or more injury diagnoses.

While the nature of both high and low threat to life injuries are dependent on the road user group involved (see Appendix 7), sprains, strains, and fractures of extremities (forearms and lower legs) are more frequently recorded for low threat to life injuries. Additional work is required to understand the nature of the forces involved in high threat to life injuries. However, drawing on the results presented in Section 1 of this report, high speed crashes may be a determining factor in the resultant nature of the injury sustained. For example, in the absence of increasing bone fragility caused by age, high energy forces are required to produce a fracture of the femur (long bones in the thigh region) (Romeo, Deitch et al. 2015). While tibia (larger long bone in the lower leg) fractures may also result from high energy forces, these fractures are also recorded in lower energy events, such as on the sports field (OrthoInfo 2010).

Between 2007 and 2012 there was a downward trend in the age standardised rate of total Serious Injury Outcome Indicator high threat to life motor vehicle traffic injuries, derived from the NMDS (Figure 20: 2007, 39.1 per 100,000 population; 2012, 31.6 per 100,000 population). This trend appeared to be mirrored by a reduction in the age standardised rate of fatal motor vehicle traffic crashes between 2007 and 2011 (2007, 9.9 per 100,000 population; 2011, 6.3 per 100,000 population). However, since 2012, the age standardised rates of fatal injuries resulting from motor vehicle traffic crashes have plateaued (stayed stable) and non-fatal Serious Injury Outcome Indicator high threat to life injuries have increased.

Understanding the difference between fatal and non-fatal injury crash circumstances is covered in the previous section of this report (Understanding the Circumstances of Serious Injuries). The primary focus of the current section is to examine the characteristics and trends in the serious non-fatal injury events, while observing some similarities between fatal and serious non-fatal injuries.

From the MVTC injury events recorded in the NMDS between July 2006 and June 2016, 869 cases (less than 1% of MVTC admissions) resulted in a death during the hospital admission. The average age of non-fatal hospital admissions was 39.1 years (std dev = 21.7), while the average age of fatal hospital admissions was 54.3 years (std dev = 27.0)[4]. Males accounted for 59% of non-fatal admissions compared with 64% of admissions resulting in death. Māori accounted for relatively similar proportions in both groups (19% of non-fatal admissions and 17% of fatal admissions). We caution against the extrapolation of these comparisons to fatal and non-fatal MVTCs in general as MVTC hospital admissions that result in the death of the injured person may not be reflective of pre-hospital MVTC fatalities.

[2] A subdural hematoma is caused by an injury to the head that tears blood vessels. Symptoms tend to fluctuate, and include: headache; episodes of confusion and drowsiness; one-sided weakness or paralysis Lethargy; enlarged or asymmetric pupils; convulsions or loss of consciousness after head injury; coma (http://medical-dictionary.thefreedictionary.com/Traumatic+subdural+haemorrhage)

[3] Bleeding over and into the substance of the brain from a ruptured artery lying under the arachnoid layer of the meninges (membranes). There is a sudden severe headache followed by loss of consciousness or other signs of neurological damage. The death rate is high (http://medical-dictionary.thefreedictionary.com/subarachnoid+haemorrhage).

[4] It is important to note that this may not correspond to the average age of ALL fatal motor vehicle traffic crash injuries. Those who die at the site, and are not admitted to hospital will not be included in this average.

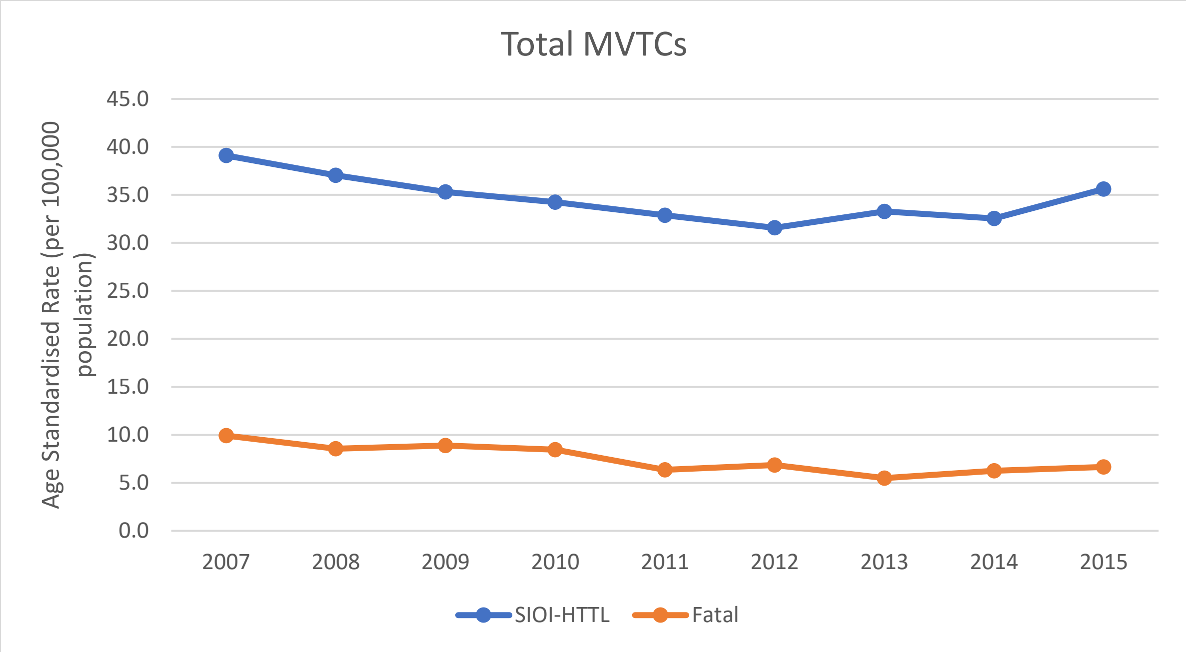

Figure 20: The Serious Injury Outcome Indicators

In comparison with the age standardised rates of Serious Injury Outcome Indicator high threat to life non-fatal motor vehicle traffic injuries which show a relatively modest decline followed by plateauing in recent years, the age standardised rate for Serious Injury Outcome Indicator low threat to life injuries has substantially reduced since 2008 and continues to do so after (Figure 21)[5]. It is important to note that the trends in low threat to life injuries may be driven by extraneous factors such as changes in service delivery (e.g., admission policies, greater use of day stay facilities for minor procedures relating to fractures), as well as actual changes in the incidence of injury in the community. Factors such as enhancements in safety technologies including car design and travel speed can influence both rates of injuries considered here.

[5] The derivation of the *Serious Injury Outcome Indicators* requires the removal of readmissions for the same injury event. When calculating the indicators, Statistics New Zealand has access to the NMDS from the year 2000 onwards. For the current investigation, the NMDS was obtained for 2006 onwards. As such, there will be injury events included in the current series that would have been considered readmissions by Statistics New Zealand as the original injury event may have occurred prior to 2006. Therefore, the trends presented in Figure 21 differ slightly from those presented in Figure 20.

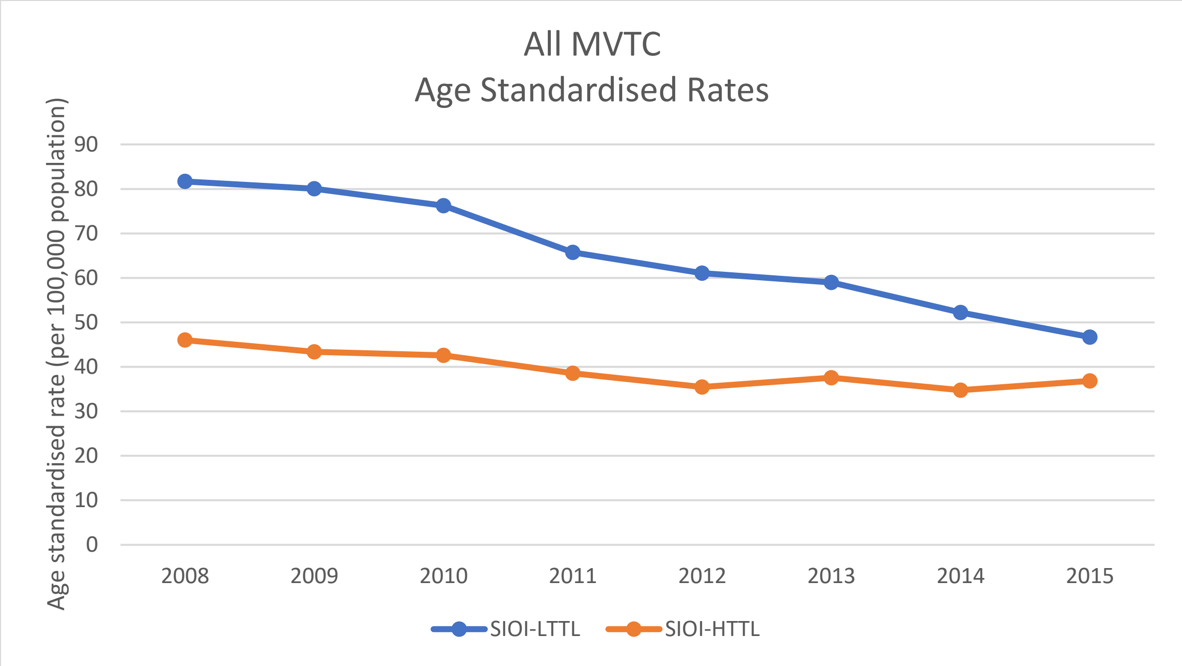

Figure 21: NMDS – non-serious vs serious injury trends (age standardised rates)

In contrast with the trends derived from the NMDS, there appears to be an increasing incidence of Injury Severity Scale low threat to life motor vehicle traffic injury in data captured in the AHTR (Figure 22). The increased number of Injury Severity Scale low threat to life events is driving the overall trends in motor vehicle traffic crash injury seen by the AHTR. There appeared to be a reduction in the frequency of Injury Severity Scale high threat to life injuries between 2006 and 2012 (from 87 Injury Severity Scale high threat to life events in 2006 to 44 in 2012), after which time the number of people seen on an annual basis has remained stable (ranging from 54 to 59 between 2014 and 2016).

It should be noted that specialist Trauma clinicians consider the Serious Injury Outcome Indicator high threat to life threshold as exceptionally high. In Figure 20, it is apparent that since 2014, there has been an increase in the age standardised rates of the Serious Injury Outcome Indicator high threat to life injury events. It is possible that the trends in trauma service admissions is reflective of the trends in the Serious Injury Outcome Indicator high threat to life.[6] The additional year of data available from the AHRT shows a substantial increase in admissions between 2015 and 2016. If trauma admissions are reflective of Serious Injury Outcome Indicator high threat to life injuries, this would imply that the increase in Serious Injury Outcome Indicator high threat to life events will continue into 2016. This supports international trends from other high income countries that show that both deaths and injuries have either stopped reducing or even increased in recent years (OECD Data 2017).

[6] The Auckland Hospital Regional Trauma Service captures injury events that occur on the roads of the Auckland region as well as injured patients that are transferred from other hospitals. As such, it is not possible to produce rates for this data as the population from which it is drawn is unknown.

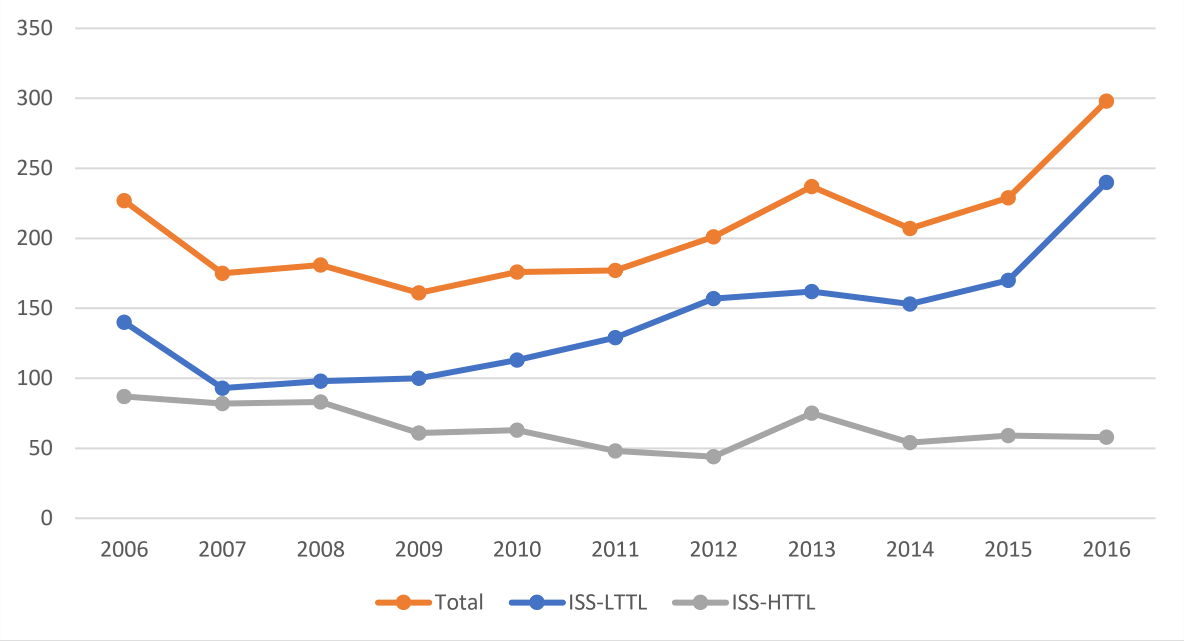

Figure 22: Auckland Regional Trauma Service – Injury Severity Scale low threat to life vs Injury Severity Scale high threat to life (frequency counts)

Road user types

The International Classification of Diseases codes used by the NMDS make it possible to identify the road user type and their role for Serious Injury Outcome Indicator high threat to life injury events. As is apparent from Figure 23, the majority of Serious Injury Outcome Indicator high threat to life injury events recorded in the NMDS are car occupants. This is not surprising given that according to the New Zealand Household Travel Survey, over 75% of people's time spent travelling involved being a driver or passenger in a car or van (Ministry of Transport 2015). Of interest is the comparison between the proportion of time which involved using a motor-bike between 2011 and 2014 (0.4%) and the prominence of Serious Injury Outcome Indicator high threat to life non-fatal motor-bike injuries over the same time period. Between 2011 and 2014, motorcycle riding accounted for approximately 0.4% of travel time, while motorcycle injuries accounted for 7% of Serious Injury Outcome Indicator high threat to life non-fatal injuries.

> *In the late 1980s, nearly one in three men had a motorcycle licence. By the late 1990s this had declined to just over one in four men with a motorcycle licence and by the early 2010s around one in five men had a motorcycle licence (Ministry of Transport 2015).*

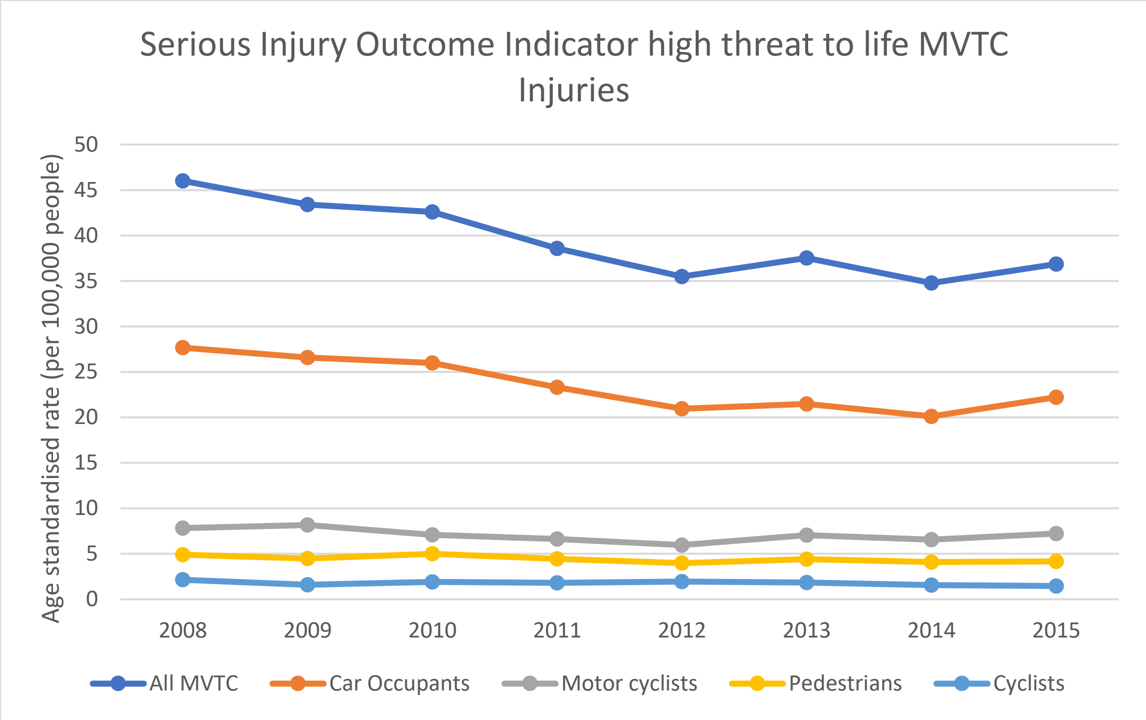

Figure 23: Serious Injury Outcome Indicator high threat to life MVTC events - road user types

Because of the predominance of the age standardised rates of Serious Injury Outcome Indicator high threat to life non-fatal injuries to car occupants, trends in rates for other road users are more difficult to see. However, a closer inspection suggests that the declining age standardised rates for motor-cyclists up to 2012 have been replaced by an increase in rates. This trend is more apparent in Figure 24 – the proportion of serious non-fatal injuries that motorcyclists account for has increased from 14% in 2006 to 20% in 2016.

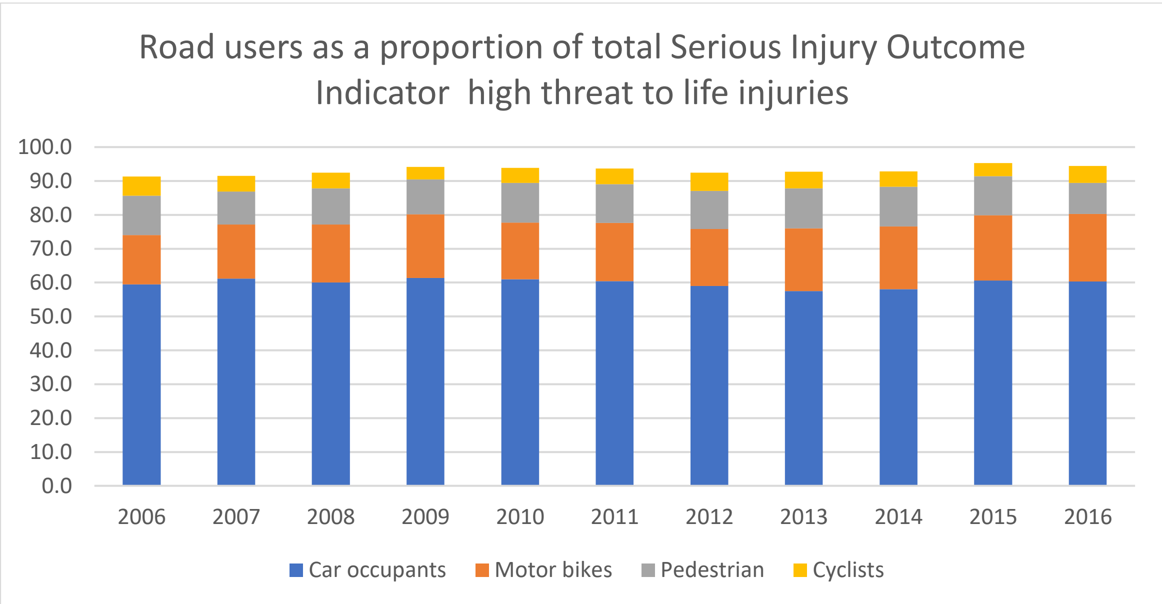

Figure 24: Percent of Serious Injury Outcome Indicator high threat to life non-fatal injuries accounted for by each road user group.

The age distribution of Serious Injury Outcome Indicator high threat to life non-fatal injuries, by road user group is presented in Table 1. As highlighted previously, car occupants account for the majority of Serious Injury Outcome Indicator high threat to life non-fatal injuries. Of those injured as car occupants, the highest proportion of injured people are aged under 25 years. Those aged under 25 years also make up the highest proportion of pedestrians injured.

Between 1997 and 2014 there has been a steady increase in the total number of kilometres motorcycled from approximately 172 million kilometres per year to 263 million kilometres per year. This increase is largely accounted for by the riding undertaken by motorcyclists aged 45 years and over (Ministry of Transport 2015). For riders aged 45 years and over, the distance travelled has increased from 20 million kilometres per year in 1997/98 to 160 million kilometres per year in the period 2009-2014. Such changes may help to explain why those aged 45 years and over account for a large proportion of the motorcyclists who are hospitalised with a Serious Injury Outcome Indicator high threat to life non-fatal injury as recorded in the NMDS (Table 1). In comparison, young people aged 15-29 years rode only 34 million kilometres per year in the period 2009-2014.

People aged 45 years and over also account for a high proportion of Serious Injury Outcome Indicator high threat to life non-fatal cyclist injuries. Unfortunately, the Household Travel Survey reports do not provide information on the approximate number of kilometres travelled by cyclists in sufficiently specified age group bands to permit a comparison of the proportion of motorcyclists aged 45 years and over who were admitted for serious non-fatal injuries with the proportional distance this road user group travels.

Table 1: Age and road user group for Serious Injury Outcome Indicator high threat to life non-fatal injuries (NMDS 2006-2016)

	Road user group			
Age group	Car occupants (n=10,297)	Motorcyclists (n=3,114)	Pedestrians (n=1,983)	Cyclists (n=832)
< 25 years	38.5	22.8	45.3	25.5
25-34	15.4	14.8	9.3	11.4
35-44	10.9	21.4	8.2	18.0
45+	35.3	41.1	37.2	45.1

Table 2 provides a description of the road user type (role) of the injured person as captured by the International Classification of Diseases *Event Description* codes, recorded in the NMDS. While over one-third of Serious Injury Outcome Indicator high threat to life injuries to car occupants occur as a result of two or more motor vehicles colliding, around one quarter are the result of a car colliding against a stationary object and another quarter due to another type of non-collision event such as the vehicle overturning. It is of interest that non-collision events (where the motorbike overturns or the rider falls without a collision event) account for the highest proportion (40%) of Serious Injury Outcome Indicator high threat to life non-fatal motorbike injuries. Given that the injuries described in this report are motor vehicle traffic injuries (and therefore occur on a road), it is unsurprising that the large majority of pedestrian and pedal cyclist injuries occur as a result of a collision between the injured person and a car, pick-up truck or van.

Table 2: ICD-10 description of injury event, Serious Injury Outcome Indicator high threat to life non-fatal injuries (NMDS 2006-2016)

Event description	%
Car occupants	
Car occupant injured in collision with car, pickup truck or van	39.2
Car occupant injured in collision with fixed or stationary object	26.9
Car occupant injured in non-collision transport accident (e.g overturning)	24.4
Car occupant injured in collision with heavy transport vehicle or bus	5.1
Car occupant injured in other and unspecified transport accident	3.4
Car occupant injured in collision with pedestrian	0.4
Car occupant injured in collision with railway train or railway vehicle	0.3
Car occupant injured in collision with 2- or 3-wheeled motor vehicle	0.2
Car occupant injured in collision with other non-motor vehicle	0.1
Motorcyclists	
Motorcycle rider injured in non-collision transport accident (fall or thrown from motorcycle without collision)	39.3
Motorcycle rider injured in collision with car, pickup truck or van	33.6
Motorcycle rider injured in collision with fixed or stationary object	15.5
Motorcycle rider injured in other and unspecified transport accidents	5.8
Motorcycle rider injured in collision with 2- or 3- wheeled motor vehicle	2.2
Motorcycle rider injured in collision with heavy transport vehicle or bus	1.9
Motorcycle rider injured in collision with pedestrian or animal	1.3
Motorcycle rider injured in collision with pedal cycle	0.2
Motorcycle rider injured in collision with railway train or railway vehicle	0.1
Motorcycle rider injured in collision with other non-motor vehicle	0.0
Pedestrians	
Pedestrian injured in collision with car, pickup truck or van	89.5
Pedestrian injured in collision with heavy transport vehicle or bus	6.5
Pedestrian injured in other and unspecified transport accidents	2.3
Pedestrian injured in collision with 2- or 3- wheeled motor vehicle	1.6
Pedal cyclists	
Pedal cyclist injured in collision with car, pickup truck or van	91.6
Pedal cyclist injured in collision with heavy transport vehicle or bus	6.8
Pedal cyclist injured in collision with 2- or 3-wheeled motor vehicle	0.9
Pedal cyclist injured in other and unspecified transport accidents	0.7

We sought to further understand the role of the road user for car and motorcyclists by identifying whether they were drivers or passengers (Table 3). For both of these road user types, the driver accounted for the largest proportion of Serious Injury Outcome Indicator high threat to life non-fatal injuries. For private motor vehicle occupants, approximately twice as much travel time involves being a driver than a passenger (Ministry of Transport 2015). This suggests that passengers are over-represented in the proportion of Serious Injury Outcome Indicator high threat to life non-fatal car occupant injuries, although the older age profile of passengers is different to drivers and may include a greater number of vulnerable people (very young and very old).

Table 3: Role of the injured person – Car occupants and motorcyclists, Serious Injury Outcome Indicator high threat to life non-fatal injuries (NMDS 2006-2016)

Role	%
Car occupant	
Driver injured in traffic accident	57.1
Passenger injured in traffic accident	35.7
Person injured while boarding or alighting	4.1
Unspecified car occupant injured in traffic accident	2.6
Person on outside of vehicle injured in traffic accident	0.5
Motorcyclist	
Driver	86.7
Unspecified rider	7.1
Passenger	5.7
Person injured while boarding	0.5

Differences between high threat to life and low threat to life injuries

The concept of "seriousness" is not static. As highlighted in Figure 25, while the majority of injury cases experience no change in their Glasgow Coma Scale score between the injury scene and admission to the emergency department, almost one-quarter experience a negative change, or a deterioration in health. Of interest is the 13% of injured people whose Glasgow Coma Scale scores increased between the injury scene and emergency department admission. Academics have queried whether blood alcohol concentrations may impact on the reliability of the Glasgow Coma Scale as a measure of severity, as intoxication may induce or mimic altered levels of consciousness. However, a review of the National Trauma Data Bank of the American College of Surgeons between 1994 and 2003, involving 108,000 patients, showed no influence of blood alcohol concentrations on Glasgow Coma Scale scores (Stuke, Diaz-Arrastia et al. 2007), suggesting that this is unlikely to be an explanation for the improvement in Glasgow Coma Scale scores seen in Figure 25.

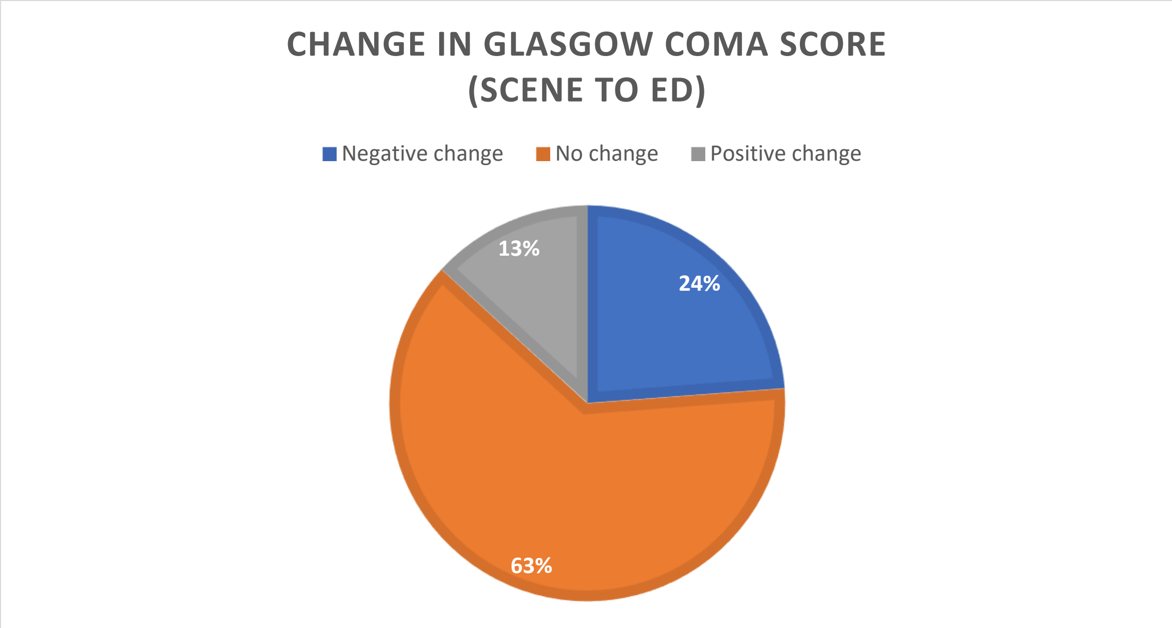

Figure 25: Changes in Glasgow Coma Scale between injury scene and emergency department (AHTR, 2006-2016)

For the majority of injury severity measures in common usage, "seriousness" is a reflection of the number of injuries sustained as well as the level of severity of the component injuries. Appendix 4 and Appendix 5 illustrate how seriousness has been conceptualised as additive (Injury Severity Score - the addition of seriousness for each additional body region) or multiplicative (ICD-based Injury Severity Score where diagnosis specific survival probabilities are multiplied together). Table 4 provides an illustration of how the severity of an injury event, using the Injury Severity Scale as an indicator of threat to life, can relate to the number of injury diagnoses recorded. For Injury Severity Scale high threat to life cases, 20% had 10 or more injury diagnoses recorded. Over half had 7 or more injury diagnoses recorded. In contrast, for Injury Severity Scale low threat to life cases, over half had one or two injury diagnoses recorded.

Table 4: Injury severity and number of injury diagnoses recorded (AHTR, 2006-2016)

	Number of injury diagnoses per injured person (% of total not serious and serious injuries)									
Injury Severity Scale score	1	2	3	4	5	6	7	8	9	10+
Injury Severity Scale low threat to life (n=1,555)	32.1	29.8	18.5	10.0	4.7	2.4	1.0	0.6	0.6	0.3
Injury Severity Scale high threat to life (n=714)	1.4	4.3	7.1	12.0	12.0	11.5	13.3	9.9	7.8	20.4

Table 5 provides an alternative measure of seriousness, where the focus is on brain health and observable deteriorations in function. In comparison with the analysis of the Injury Severity Scale (a reflection of the anatomical nature injuries in the whole body) presented in Table 4, the Glasgow Coma Scale table is notable for the *lack* of difference in the number of injuries sustained. For both

Glasgow Coma Scale high threat to life and Glasgow Coma Scale low threat to life injury events, almost half of the injured had only one or two injury diagnoses. Slightly over 10% of Glasgow Coma Scale high threat to life cases had 10 or more other injury diagnoses.

Table 5: Glasgow Coma Scale score and number of injury diagnoses recorded (AHTR, 2006-2016)

	Number of injury diagnoses per injured person (% of total not serious and serious injuries)									
Glasgow Coma Scale severity	1	2	3	4	5	6	7	8	9	10+
Glasgow Coma Scale low threat to life (n=1,915)	22.1	22.1	15.9	10.5	7.0	5.4	4.6	3.7	2.7	5.9
Glasgow Coma Scale high threat to life (n=354)	24.0	20.1	9.9	11.6	6.8	4.2	5.9	3.1	4.0	10.5

Whilst not apparent from Table 4, injuries to the head, neck and cervical spine are a significant determinant of the Injury Severity Scale score. Severe injuries in these anatomical locations (as represented by the Maximum *Abbreviated Injury Score*) have a strong influence on the combined score represented by the Injury Severity Scale. Over half (59%) of cases recorded as Injury Severity Scale high threat to life had head, neck or cervical spine injuries that were considered severe or critical. Approximately 37% of major trauma cases sustained thoracic (ribs, breast bone, thoracic vertebrae and organs contained within) injuries considered severe or critical (Table 6).

Table 6: Maximum AIS score for body regions by Injury Severity Scale severity (AHTR, 2006-2016)[7]

	Maximum AIS score						
	1 minor N (%)	2 moderate N (%)	3 serious N (%)	4 severe N (%)	5 critical N (%)	6 maximal N (%)	Total injuries
Head / neck / cervical spine							
Injury Severity Scale low threat to life	74 (14)	342 (67)	98 (19)	0 (0)	0 (0)	0 (0)	514
Injury Severity Scale high threat to life	0 (0)	105 (20)	108 (20)	197 (37)	116 (22)	1 (0)	527
Face							
Injury Severity Scale low threat to life	65 (57)	44 (39)	5 (4)	0 (0)	0 (0)	0 (0)	114
Injury Severity Scale high threat to life	53 (27)	113 (57)	31 (16)	0 (0)	0 (0)	0 (0)	197

[7] AIS scores are only recorded for body regions where an injury has occurred. Therefore, the total number of injuries in each body region is variable.

Thorax including thoracic spine							
Injury Severity Scale low threat to life	40 (10)	209 (54)	141 (36)	0 (0)	0 (0)	0 (0)	390
Injury Severity Scale high threat to life	12 (2)	58 (11)	248 (49)	153 (30)	37 (7)	0 (0)	508
Abdomen including lumbar spine							
Injury Severity Scale low threat to life	7 (4)	126 (75)	36 (21)	0 (0)	0 (0)	0 (0)	169
Injury Severity Scale high threat to life	0 (0)	154 (48)	100 (31)	55 (17)	14 (4)	0 (0)	323
Extremities (includes pelvis)							
Injury Severity Scale low threat to life	37 (6)	426 (71)	138 (23)	0 (0)	0 (0)	0 (0)	601
Injury Severity Scale high threat to life	9 (2)	227 (50)	215 (48)	1 (0)	0 (0)	0 (0)	452
External (skin, soft tissue)							
Injury Severity Scale low threat to life	678 (100)	3 (0)	0 (0)	0 (0)	0 (0)	0 (0)	681
Injury Severity Scale high threat to life	223 (99)	3 (1)	0 (0)	0 (0)	0 (0)	0 (0)	226

Within the AHTR data set, information is available on the use of helmets and safety belts, and presence of airbags in vehicles (Table 7). However, the trauma service collating these data caution against considering the data recorded for these particular variables to be generalizable. There is a significant proportion of missing or incomplete information for these variables which are reliant on completeness and reliability of the information recorded in and extracted from the ambulance run sheet. The analysis below has been presented as an example of the kind of evaluation that could be possible should a comprehensive data collection system become available, or if it was possible to link between data contained within the CAS and Trauma Registry data.

As we do not have information on people who died before admission as well as those who did not receive injuries or suffered only minor trauma, an examination of the AHTR would not provide evidence of the effectiveness of these protective devices. There is a large body of published research evidence that attests to the benefits of these devices. However, the analyses suggest that those with more serious injuries were less likely than those with less serious injuries to be using helmets or seatbelts. Helmet use was recorded in only in a small number of cases (n=198). Within this sub-cohort, 82% of cases considered to have an Injury Severity Scale low threat to life injury were wearing a helmet, while only 58% of those with an Injury Severity Scale high threat to life were wearing a helmet. Similarly, 79% of those considered to have an Injury Severity Scale low threat to life injury were wearing a seatbelt compared with 64% of those who sustained an Injury Severity Scale high threat to life injury are low threat to life. Further detail concerning the injury event may help to understand if seatbelt use by Injury Severity Scale high threat to life cases who were not wearing these would have been sufficient to prevent death. More particularly, the fact that a third of people suffering injuries which pose a high threat to life were not wearing as widely acknowledged a protective device as seatbelts requires attention to the societal factors involved.

Table 7: Use of protective devices (AHTR, 2006-2016)

Injury Severity Scale Severity	Seatbelt use (recorded for 1,672 cases)		Airbags (recorded for 520 cases)		Helmet use (recorded for 198 cases)	
	No	Yes	No	Yes	No	Yes
Injury Severity Scale low threat to life	21%	79%	46%	54%	18%	82%
Injury Severity Scale high threat to life	36%	64%	51%	49%	42%	58%

It is also important to note that while the use of protective equipment may not have been sufficient to prevent Injury Severity Scale high threat to life injuries, many other factors can also contribute to the severity of the injuries. For example, bone fragility, especially as people age, may be a determinant of the number of injuries sustained (Dischinger, Ryb et al. 2006) in addition to the speed and forces involved in the injury event.

In Appendix 7, Appendix 8, Appendix 9 and Appendix 10, the most frequently recorded Serious Injury Outcome Indicator low threat to life injury diagnoses are compared with the most frequently recorded Serious Injury Outcome Indicator high threat to life injury diagnoses. Only principal diagnoses are listed[8]. Comparisons are made across road user types, across age groups, and by age groups for car occupants and motorcyclists, respectively.

- As indicated in Table 6, head injuries are a prominent feature of Serious Injury Outcome Indicator high threat to life injuries across all age groups and across all road user types, while sprains, strains and limb fractures are a common feature of Serious Injury Outcome Indicator low threat to life injuries.
- *Fracture of the Shaft of the Clavicle* (a fracture in the middle section of the collar bone) was a common injury in both Serious Injury Outcome Indicator low threat to life and Serious Injury Outcome Indicator high threat to life cases. When interpreting this information, it is important to acknowledge that the threat to life may have been due to co-occurring injuries rather than those most commonly observed. Therefore, the frequency of a fractured clavicle may reflect the type of fall that occurs with a motorbike crash, but not necessarily the type of injury that is a threat to life.
- The potential influence of increasing frailty can be seen in the common injury diagnoses (multiple rib fractures and fractures of cervical vertebrae (vertebrae within the neck)) for Serious Injury Outcome Indicator high threat to life cases aged over 45 years.
- The types of injuries recorded for high and low threat to life injury events within road user groups may be a reflection of the forces involved in the injury events. For example, a contusion of the thorax (region between the neck and the abdomen), with additional force applied (either through speed, the nature of the object hit, or both) may result in a fracture

[8] Up to 99 diagnosis or operation codes can be recorded in the NMDS for each injury event. The "principal diagnosis" is that considered the main reason for admission to hospital.

of the sternum[9]. Similarly, a sprain or strain of the cervical spine may result in a fracture of cervical vertebrae with additional force applied.

The Major Trauma Registry which is being implemented currently will allow reporting of the incidence of major trauma at the national level and opportunities to explore regional and other variations of relevance. The coverage of District Health Boards providing data to this registry is rapidly increasing providing an important opportunity for population-level data in the near future.

Discussion

The aim of Section Two of this report was to develop a profile of road crash injuries to better understand the proportion and nature of serious injuries that could be considered life-altering trauma, compared with less-extreme injuries like a broken bone. The concept of seriousness may take on many different forms, including threat to life, long term impact on an individual's quality of life, length of stay and cost or medical care, and / or long term psychological impact. In this report we have focussed on threat to life. In general, high threat to life injury events are characterised by either (a) a higher number of individual injuries, and / or (b) a head injury. Over 20% of those recorded as high threat to life had ten or more injury diagnoses. Among people with brain injuries who were defined as having a high threat to life, the brain injury was the only injury diagnosis.

Data from the NMDS highlighted a clear relationship between age and injury severity. Road users aged over 45 years accounted for over 40% of motorcyclist and pedal cyclist high threat to life injuries. While this pattern may be influenced by the fact that there are increased numbers of older road users on the road (Ministry of Transport 2009), it may also be influenced by increased bone fragility amongst older road users.

Aside from the number of separate injuries sustained, one of the key determinants of threat to life appeared to be the impact of forces resulting from the crash event. It is apparent from the injuries listed in the tables in Appendix 7 that while the same part of the body might be injured in high threat to life and low threat to life injuries, it appears that the forces involved in the injury event make for more substantive injuries. For example, a sprain or strain of the cervical spine (Figure 26) was the most frequently recorded low threat to life injury for car occupants. While a fracture of the second cervical vertebrae was frequently recorded in high threat to life injuries. Fractured C2 vertebrae most frequently occur in children and the elderly (Kalantar 2013) and are associated with muscle weakness or paralysis in the trunk, arms or legs, loss of feeling in the trunk, arms, or legs, breathing problems, problems with heart rate and blood pressure, digestive problems, loss of bowel and bladder function and sexual dysfunction (Johns Hopkins Medicine). Similarly, injuries impacting on the thorax and sternum regions (Figure 27) may be seat-belt related. In low threat to life injury events, these result in a contusion of the thorax (a bruise of the chest wall), while high threat to life event result in fracture of the sternum.

[9] The sternum, commonly known as the breastbone, is a long, narrow flat bone that serves as the keystone of the rib cage and stabilizes the thoracic skeleton (http://www.innerbody.com/image_chest1/skel16.html)

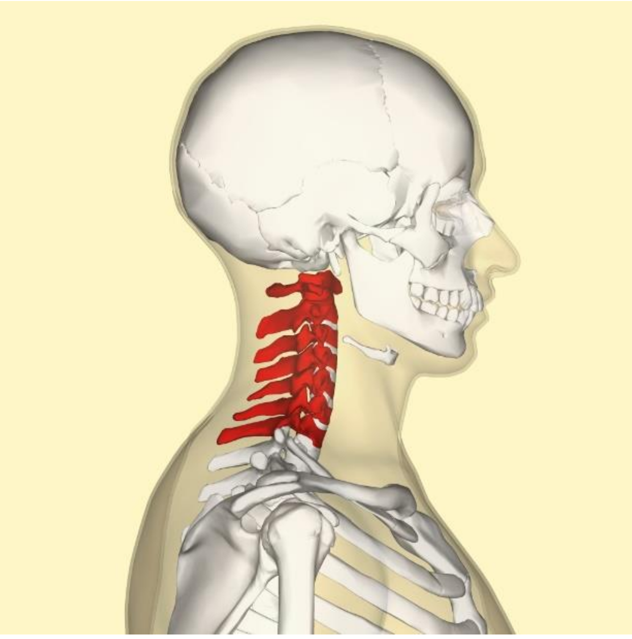

Figure 26: Cervical spine and vertebrae (vertebrae are numbered from 1 to 7, top to bottom)[10]

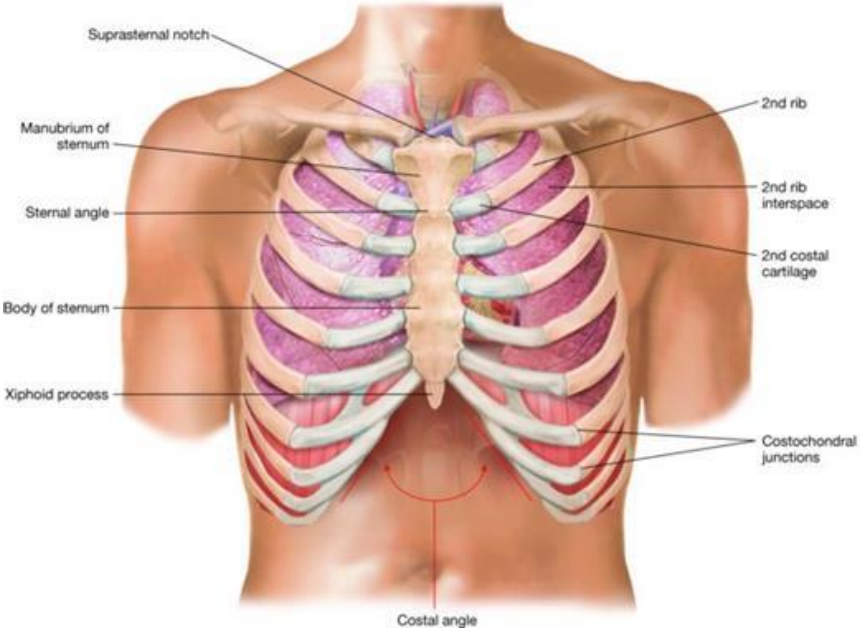

Figure 27: The thorax[11]

[10] https://en.wikipedia.org/wiki/Cervical_vertebrae
[11] https://healtheappointments.com/chapter-8-the-thorax-and-lungs-essays/

CONCLUSION FOR PARTS 1 AND 2

Although the two parts to this report were carried out as separate studies, there are some common themes that have implications for our understanding of, and response to, serious injuries. There are also implications for further work. Here, key themes and suggestions for future work are suggested by both studies.

It is important to consider system factors together. We have seen synergistic effects of the characteristics of the road user (e.g. age), their mode of transport and other system factors (such as road environment) that will contribute to the types of injuries sustained. One factor alone seldom determines the seriousness of injuries sustained.

There are clearly crash scenarios that are more likely to lead to high threat to life injuries and fatalities. For example, high impact decelerations caused by high travel speed and hitting roadside objects and oncoming vehicles are much more likely to result in high threat to life casualties and fatalities. In low threat to life injury cases it is likely that at least one or more system factors work to prevent very serious injuries or death. The present research suggests that further emphasis needs to be placed on the various analyses and programmes that exist which identify environments, speeds and travel modes that are associated with higher severity casualty outcomes, so that system improvement practices are more likely to result in a Safe System. Our knowledge of situations that are likely to result in high severity crashes is reasonably robust, but this often does not translate into Safe System practices.

It would be useful to understand more about the injuries that result from certain scenarios (e.g. vehicle rollovers). Likewise, understanding more about the contexts can provide important information about the factors predicting certain injuries (for example, which crash situations are leading to high threat to life head injuries?). This suggests that additional information could be derived by linking data sets to draw on the strengths of each and produce a more complete picture of serious injury crashes and outcomes.

Given the prominence of head injuries in Part 2, further work is required to understand how to reduce the risk of head injuries - possibly drawing on data linkage as outlined above. For some (but certainly not all) motorcycle and cycle crashes there is a degree of protection from helmets. However, helmets seldom protect from internal rotational forces and shearing which are the cause of many “brain bleeds” (subdural and subarachnoid haematoma). Further, wearing a helmet in a car or truck is not feasible and so other system factors may need to play more of a part in mitigating head injuries.

Finally, this research has taken a Safe System view of serious injury crashes (compared with fatal crashes) and the hospital injuries that result from motor vehicle crashes. The latent conditions and pre-cursors to crashes are a natural next step for enquiry (for example, why do some still choose not to wear seatbelts when the risk of death when they aren’t worn is so high?). At the other end of the ‘casualty pipeline’ the ongoing implications of crashes on people’s lives is of interest, including disability and loss of opportunity. If a goal is to reduce the overall burden of motor vehicle crashes on the lives of New Zealanders, then effort in all aspects of the ‘casualty pipeline’ might be needed.

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APPENDICIES

Appendix 1: Literature for the nature of serious crashes

Crashes are complex and the factors that influence injury severity and fatality are many and varied. Likely due to the limitations of matching crash data with hospitalisation data, the literature does not conclusively provide information about crash type and injury type and severity. However, there are strong trends which indicate that particular risk factors are more likely to be associated with particular injury types, or crash outcomes.

For older drivers, due to increased frailty, the outcome of the crash is more likely to result in that driver’s fatality, or increases the risk of all injury types (O'Donnell and Connor 1996, Abdel-Aty, Chen et al. 1998, Zhang, Lindsay et al. 2000, Abdelwahab and Abdel-Aty 2001, Bédard, Guyatt et al. 2002, Braver and Trempel 2004, Delen, Sharda et al. 2006, Mohan 2006, Huang, Chin et al. 2008, Dupont, Martensen et al. 2010, Funk, Cormier et al. 2012, Abu-Zidan and Eid 2015, de Pont 2016, Usman, Fu et al. 2016).

Young, inexperienced drivers have been shown to be more crash involved (Dobson, Brown et al. 1999, Huang, Chin et al. 2008, Ministry of Transport 2012). Indeed for young NZ drivers, the presence of passengers, particularly a combination of male and female, dramatically increases the probability of serious and fatal injuries (Weiss, Kaplan et al. 2014).

Gender is a factor in the severity and type of injury sustained. Although it has been shown that females are more likely to receive serious injuries than males (O'Donnell and Connor 1996, Abdelwahab and Abdel-Aty 2001, Abdel-Aty 2003, Yau 2004, Delen, Sharda et al. 2006, Mohan 2006, Yasmin, Eluru et al. 2015, Usman, Fu et al. 2016), crahses that result in severe injuries do not depend in the gender of the driver (Delen, Sharda et al. 2006). However, a higher proportion of males die in crashes than females (Tavris, Kuhn et al. 2001, Kmet, Brasher et al. 2003, Ministry of Transport 2012).

The behaviour of occupants in the vehicle has a strong influence on the outcome of a crash (Wundersitz and Baldock 2011, Ministry of Transport 2012, Wundersitz, Baldock et al. 2014). This is seen in relation to seatbelt non-use for the driver and passengers, the presence of alcohol in the driver’s bloodstream, and reckless driving behaviour.

In relation to restraint non-use, it has been shown that all vehicle occupants are at a higher risk of injury severity, with decreased survival chances (O'Donnell and Connor 1996, Bédard, Guyatt et al. 2002, Abdel-Aty 2003, Delen, Sharda et al. 2006, Gloeckner, Moore et al. 2006, Mohan 2006, Dupont, Martensen et al. 2010, Siskind, Steinhardt et al. 2011, Stigson, Kullgren et al. 2011, Funk, Cormier et al. 2012, Weiss, Kaplan et al. 2014, Yasmin, Eluru et al. 2015, Usman, Fu et al. 2016). Vehicle occupants not wearning seatbelts are at an increased risk of sustaining a cervical spine injury (Funk, Cormier et al. 2012) and being ejected from the vehicle (Abu-Zidan and Eid 2015). Ejection is associated with a higher risk of serious injury (Yasmin, Eluru et al. 2015).

While the literature is in agreement that the presence of alcohol in the driver’s bloodstream is associated with a higher risk of fatality or serious injuries (O'Donnell and Connor 1996, Bédard, Guyatt et al. 2002, Delen, Sharda et al. 2006, Mohan 2006, Siskind, Steinhardt et al. 2011, Wundersitz and Baldock 2011, Ministry of Transport 2012, Weiss, Kaplan et al. 2014, Yasmin, Eluru et al. 2015, Usman, Fu et al. 2016), the literature is inconsistant about the level of alcohol concentration in the driver’s blood. Reckless driving behaviour and violations of the road rules have been shown to increase the liklihood of a fatality in a crash (Siskind, Steinhardt et al. 2011, Wundersitz and Baldock 2011, Weiss, Kaplan et al. 2014).

Car occupants’ survival chances and injury severity are negatively associated with the age of the vehicle (Yau 2004, Dupont, Martensen et al. 2010, Yasmin, Eluru et al. 2015, Usman, Fu et al. 2016).

Faster speeds are a commonly cited factor in the literature as a contributor to the increased severity outcome of a crash (O'Donnell and Connor 1996, Bédard, Guyatt et al. 2002, Taylor, Baruya et al.

2002, Abdel-Aty 2003, Mohan 2006, Haleem and Abdel-Aty 2010, Siskind, Steinhardt et al. 2011, Abu-Zidan and Eid 2015, Yasmin, Eluru et al. 2015, de Pont 2016, Usman, Fu et al. 2016).

In relation to passenger vehicles, their make, length, and mass are contributing factors in the outcome of a crash. For example, in single-vehicle crashes, SUV/4x4s are less safe than passenger cars as they are more likely to roll (Kockelman and Kweon 2002, Wenzel and Ross 2005). However, in a two-vehicle crash between a SUV/4x4 and a passenger car, the mass ratio will have more severe outcomes for the occupants of the passenger car (Evans and Wasielewski 1987, Joksch 1998, Kockelman and Kweon 2002, Wenzel and Ross 2005, Huang, Chin et al. 2008, Tolouei, Maher et al. 2013).

The type of crash has an influence on motor vehicle occupants' injury risk. Rollover crashes are associated with a high risk of injury (Delen, Sharda et al. 2006, Stigson, Gustafsson et al. 2015), in particular cervical spine injuries (Funk, Cormier et al. 2012, Ridella, Rupp et al. 2012). In a crash where one vehicle was stopped prior to the incident, that driver would have a higher probability of sustaining an injury to the driver in motion (Yasmin, Eluru et al. 2015). Colliding with a large non-frangible object, such as a tree, wall, or building results in a higher probability of instant death (Yasmin, Eluru et al. 2015). Finally, a frontal impact (but not head-on) is associated with an increased survival probability to a side impact, especially an impact on the driver's side (Farmer, Braver et al. 1997, Joksch 1998, Bédard, Guyatt et al. 2002, Dupont, Martensen et al. 2010). In frontal crash types, there is a high rate of head injuries (Carter, Flannagan et al. 2014, Stigson, Gustafsson et al. 2015), thoracic injuries (Morris, Welsh et al. 2003, Ridella, Rupp et al. 2012, Carter, Flannagan et al. 2014) and lower extremity injuries (Kuppa and Fessahaie 2003).

For vehicle occupants with a high BMI, there is an increased risk of serious spine injury and fatality (Funk, Cormier et al. 2012). Obese occupants are more likely to experience lower extremity injuries and increased seatbelt loading and damage to the lower thorax region (Carter, Flannagan et al. 2014).

Studies have shown that peak hours are the safest time to travel, with the lowest injury severity rates recorded at these times (Huang, Chin et al. 2008, Yasmin, Eluru et al. 2015), likely due to slower speeds and higher vehicle density (Usman, Fu et al. 2016). Conversely, night-time travel, especially between midnight and 6am is a factor which increases injury risk in a crah (Huang, Chin et al. 2008, Yasmin, Eluru et al. 2015). Coupled with time of travel, driver fatigue is also associated with not only the increased liklihood of a crash (Lee, Howard et al. 2016) but also the increased risk of a serious injury or fatality (Connor, Norton et al. 2002), particularly a fatality in two-vehicle crashes (Weiss, Kaplan et al. 2014).

Within the road environment are numerous factors that influence the liklihood and severity of a crash. A study in Singapore deomnstrated that crash severity was increased by 69% when there was poor street lighting (Huang, Chin et al. 2008). The presence of sharp bends (Taylor, Baruya et al. 2002) has been shown to increase the frequency of single-vehicle crashes. Rural roads are associated with higher fatality rates (Kmet, Brasher et al. 2003, Haleem and Abdel-Aty 2010, Wundersitz and Baldock 2011). And an increase in the number of lanes has been shown to decrease the probability of a fatality and lessen the severity of injuries sustained (Usman, Fu et al. 2016).

Intersection design is another factor than affects the likelihood and severity of a crash. It was found that although traffic control devices decreased the likelihood of a serious crash (Yasmin, Eluru et al. 2015), this did not extend to red light cameras which were found to increase severity risk (Huang, Chin et al. 2008). However, the authors did note that this may be confounded by the intersection already being dangerous. A lack of a stop line on the minor approach of an unsignalised intersection fas found to increase injury and fatality risk (Haleem and Abdel-Aty 2010). Finally, T and Y intersections were found to have a greater injury severity risk than other intersection types (Huang, Chin et al. 2008).

Appendix 2: Overview of CAS Analysis

Table 8: Gender

	Fatal (100 crashes)	Serious (200 crashes)
Male	64%	60%
Female	36%	40%

Table 9: Road surface, light, and weather conditions

	Fatal (100 crashes)	Serious (200 crashes)
Road surface - Dry	82%	71%
Road surface - Wet	16%	30%
Road surface - Ice/ snow	2%	0%
Light conditions - Bright sun	36%	33%
Light conditions - Dark	42%	32%
Light conditions - Overcast	16%	28%
Light conditions - Twilight	5%	6%
Light conditions - Unknown	1%	2%
Weather - Fine	86%	72%
Weather - Light Rain	8%	20%
Weather - Heavy rain	3%	4%
Weather - Mist	1%	3%
Weather - Unknown	2%	3%

Although there are some differences in the road, light, and weather conditions, these are not considered to affect the outcome of the crashes.

Table 10: Intersections and traffic control

	Fatal (100 crashes)	Serious (200 crashes)
Intersection - No	82%	68%
Intersection - Roundabout	1%	3%
Intersection - T, X, Y	15%	24%
Driveway	2%	6%
Traffic control - Give way	10%	15%
Traffic control - Stop	5%	3%
Traffic control - Traffic signal	0%	7%

Appendix 3: Criteria for Trauma Call

A: A mandatory trauma call

Will be made when there is one or more of:

1. RT call

The emergency department is notified of the imminent arrival of an unstable trauma patient (status 1 or 2). Status one patients have an immediate threat to life. Examples would include any of the following - obstructed airway or airway needing intervention to prevent obstruction, severe stridor, severe respiratory distress, shock unresponsive to fluid loading, multisystem trauma with very abnormal vital signs, post cardiac arrest with coma, cardiogenic shock, coma with GCS less than or equal to nine. Status two patients have a potential threat to life. Examples would include any of the following - moderate stridor, moderate respiratory distress, shock responsive to fluid loading, anyone meeting our pre-hospital definition of major trauma but with normal or near normal vital signs, post cardiac arrest but awake, cardiac chest pain unrelieved by nitrates and oxygen alone, abnormal GCS but greater than nine.

2. Physiology

- Respiratory rate < 10 or > 29
- Systolic blood pressure < 90 mmHg
- Glasgow Coma Scale < 13

These physiological parameters may be met in the ambulance, noted at triage or deteriorated to in the emergency department.

3. Transfer

Major trauma patient from another Hospital coming to the Emergency Dept.

4. Multiple Casualties

When the Emergency Department is forewarned of the imminent simultaneous arrival of six or more trauma patients, irrespective of their suspected injury severity.

5. Injury Pattern

- Penetrating injury to the head, neck or torso
- Flail chest
- Complex pelvic injury
- Two or more proximal long bone fractures
- Traumatic amputation proximal to knee or elbow
- Major crush injury
- Paraplegia or quadriplegia

B: A discretionary trauma call

These can be made by the Emergency Medicine registrar or consultant. This may be made for mechanism, physiology, co-morbidities or a combination of these. These might include:

- Fall > 3 metres
- Cyclist or motorcyclist versus car
- Pedestrian versus car or train
- Ejection from a vehicle
- Entrapment > 30 minutes

- Fatality in the vehicle
- Beta-blockers
- Relative hypotension
- Anticoagulation
- Especially when present in an elderly patient

From http://www.trauma.co.nz/index.php/guidelines/part-1-trauma-calls/ accessed 8 June 2017. Last updated on 28/11/2011

Appendix 4: Calculation of the International Classification of Disease (ICD)-based Injury Severity Score

From (Statistics New Zealand 2011)

The ICD-based Injury Severity Score (ICISS) is a survival probability measure. It is a useful tool for estimating injury severity from administrative data (Cryer, Langley et al. 2004).

The ICISS method

ICISS methodology involves estimating the probability of surviving an injury as a product of the survival probabilities for all of the injury diagnoses for an individual hospital event. Diagnostic specific survival probabilities (DSP) are calculated by dividing the number of people who survive with a specific diagnosis by the total number of people assigned that diagnosis over a defined time period.

DSP = Number of times a given diagnosis code occurs in a surviving patient

Total number of occurrences of that injury diagnosis code in the dataset

The ICISS itself is the product of all the DSPs associated with the injury diagnoses listed for a hospital event. For example, a patient admitted with a diagnosis of concussion alone (ICD-10 code S0600) will have an ICISS equal to the SRR for that diagnosis (DSP = 0.997). However, the ICISS for a patient admitted with the diagnoses of concussion and a skull fracture (ICD-10 code S021, ICISS = 0.891) will be the product of the SRRs for each of these diagnoses. In this case, the ICISS is 0.889 (0.997 x 0.891).

Appendix 5: The Abbreviated Injury Scale and Injury Severity Score

Adapted from "The Injury Severity Score revisited" (Copes, Champion et al. 1988)

The Abbreviated Injury Scale (AIS) is an anatomically based consensus-derived global severity scoring system that classifies each injury in body regions according to their relative severity on a six-point ordinal scale:

1. Minor
2. Moderate
3. Serious
4. Severe
5. Critical
6. Maximal (currently untreatable).

The Injury Severity Score is based (see below) upon the Abbreviated Injury Scale (AIS). To calculate an ISS for an injured person, the body is divided into six ISS body regions. These body regions are:

- Head or neck - including cervical spine
- Face - including the facial skeleton, nose, mouth, eyes and ears
- Chest - thoracic spine and diaphragm
- Abdomen or pelvic contents - abdominal organs and lumbar spine
- Extremities or pelvic girdle - pelvic skeleton
- External – skin and soft tissues

To calculate an ISS, the highest AIS severity code in each of the three most severely injured ISS body regions are squared and added together.

ISS = A2 + B2 + C2

where A, B, C are the AIS scores of the three most injured severely injured ISS body regions.

Possible ISS scores ranges from 1 to 75. A score of 75 is equivalent to a maximum AIS of 5 in each of the most severely injured regions. If any of the three scores is a 6 (currently untreatable), the score is automatically set at 75.

Appendix 6: The Glasgow Coma Scale

From Glasgow Coma Scale (Teasdale and Jennett 1974, Rowlett 2000, Glynn and Drake 2012).

Glasgow Coma Scale

	1	2	3	4	5	6
Eye	Does not open eyes	Opens eyes in response to painful stimuli	Opens eyes in response to voice	Opens eyes spontaneously	N/A	N/A
Verbal	Makes no sounds	Incomprehensible sounds	Utters incoherent words	Confused, disoriented	Oriented, converses normally	N/A
Motor	Makes no movements	Extension to painful stimuli (decerebrate response)	Abnormal flexion to painful stimuli (decorticate response)	Flexion / Withdrawal to painful stimuli	Localizes painful stimuli	Obeys commands

The scale is composed of three tests: eye, verbal and motor responses. The three values separately as well as their sum are considered. The lowest possible GCS (the sum) is 3 (deep coma or death), while the highest is 15 (fully awake person).

Eye response

There are four grades starting with the most severe:

1. No eye opening
2. Eye opening in response to pain stimulus. (a peripheral pain stimulus, such as squeezing the lunula area of the patient's fingernail is more effective than a central stimulus such as a trapezius squeeze, due to a grimacing effect).[4]
3. Eye opening to speech. (Not to be confused with the awakening of a sleeping person; such patients receive a score of 4, not 3.)
4. Eyes opening spontaneously

Verbal response

There are five grades starting with the most severe:

1. No verbal response
2. Incomprehensible sounds. (Moaning but no words.)
3. Inappropriate words. (Random or exclamatory articulated speech, but no conversational exchange. Speaks words but no sentences.)
4. Confused. (The patient responds to questions coherently but there is some disorientation and confusion.)
5. Oriented. (Patient responds coherently and appropriately to questions such as the patient's name and age, where they are and why, the year, month, etc.)

Motor response

There are six grades:

1. No motor response
2. Decerebrate posturing accentuated by pain (extensor response: adduction of arm, internal rotation of shoulder, pronation of forearm and extension at elbow, flexion of wrist and fingers, leg extension, plantarflexion of foot)
3. Decorticate posturing accentuated by pain (flexor response: internal rotation of shoulder, flexion of forearm and wrist with clenched fist, leg extension, plantarflexion of foot)
4. Withdrawal from pain (Absence of abnormal posturing; unable to lift hand past chin with supraorbital pain but does pull away when nailbed is pinched)
5. Localizes to pain (Purposeful movements towards painful stimuli; e.g., brings hand up beyond chin when supraorbital pressure applied.)
6. Obeys commands (The patient does simple things as asked.)

Appendix 7: SIOI LTTL and HTTL injury diagnoses by road user type

SIOI-LTTL			**SIOI-HTTL**		
Diagnosis code	Freq	Diagnosis description	Diagnosis code	Freq	Diagnosis description
Car occupant					
S134	1,145	Sprain or strain of cervical spine	S222	424	Fracture of sternum
S202	1,001	Contusion of thorax	S065	346	Traumatic subdural haemorrhage
S199	640	Unspecified injury of neck	S0601	343	Loss of consciousness unspecified duration
S399	635	Unspecified injury of abdomen, lower back and pelvis	S121	303	Fracture of second cervical vertebra
S099	606	Unspecified injury of head	S066	296	Traumatic subarachnoid haemorrhage
Motorbike					
S8218	296	Other fracture of upper end of tibia	S723	133	Fracture of shaft of femur
S8221	292	Fracture of shaft of tibuia with fracture of fibula	S2244	100	Multiple rib fractures involving four or more ribs
S810	209	Open wound of knee	S270	99	Traumatic pneumothorax
S826	207	Fracture of lateral malleolus	S0601	82	Loss of consciousness unspecified duration
S4202	204	Fracture of shaft of clavical	S066	77	Traumatic subarachnoid haemorrhage
Pedestrians					
S8221	200	Fracture of shaft of tibuia with fracture of fibula	S065	110	Traumatic subdural haemorrhage
S8218	139	Other fracture of upper end of tibia	S066	101	Traumatic subarachnoid haemorrhage
S0602	84	Loss of consciousness, brief duration (<30min)	S325	83	Fracture of pubis
S825	84	Fracture of medial malleolus	S021	70	Fracture of base of skull
S8281	84	Bimalleolar fracture, ankle	S010	69	Open would of scalp
Cyclist					

S0602	49	Loss of consciousness, brief duration (<30min)	S0602	50	Loss of consciousness, brief duration (<30min)
S0600	45	Concussion	S0601	35	Loss of consciousness unspecified duration
S8218	43	Other fracture of upper end of tibia	S065	26	Traumatic subdural haemorrhage
S099	40	Unspecified injury of head	S0600	23	Concussion
S8221	40	Fracture of shaft of tibia with fracture of fibula	S066	22	Traumatic subarachnoid haemorrhage

Appendix 8: SIOI LTTL and HTTL injury diagnoses by age group

SIOI-LTTL			**SIOI-HTTL**		
Diagnosis code	Freq	Diagnosis description	Diagnosis code	Freq	Diagnosis description
< 25 years					
S099	468	Unspecified injury of head	S0601	263	Loss of consciousness unspecified duration
S134	426	Sprain or strain of cervical spine	S723	238	Fracture of shaft of femur
S0600	388	Concussion	S065	225	Traumatic subdural haemorrhage
S0602	387	Loss of consciousness, brief duration (<30min)	S066	193	Traumatic subarachnoid haemorrhage
S399	316	Unspecified injury of abdomen, lower back and pelvis	S010	187	Open would of scalp
25-34 years					
S134	239	Sprain or strain of cervical spine	S723	91	Fracture of shaft of femur
S399	190	Unspecified injury of abdomen, lower back and pelvis	S0601	85	Loss of consciousness unspecified duration
S199	140	Unspecified injury of neck	S066	84	Traumatic subarachnoid haemorrhage
S0600	133	Concussion	S010	74	Open would of scalp
S099	125	Unspecified injury of head	S0602	61	Loss of consciousness, brief duration (<30min)
35-44 years					
S134	218	Sprain or strain of cervical spine	S066	66	Traumatic subarachnoid haemorrhage
S202	128	Contusion of thorax	S723	66	Fracture of shaft of femur
S8218	102	Other fracture of upper end of tibia	S0601	62	Loss of consciousness unspecified duration

S0600	98	Concussion	S065	59	Traumatic subdural haemorrhage
S199	98	Unspecified injury of neck	S270	50	Traumatic pneumothorax
> 45 years					
S202	587	Contusion of thorax	S222	350	Fracture of sternum
S222	406	Fracture of sternum	S065	264	Traumatic subdural haemorrhage
S134	342	Sprain or strain of cervical spine	S2244	239	Multiple rib fractures involving four or more ribs
S8218	302	Other fracture of upper end of tibia	S121	219	Fracture of second cervical vertebra
S299	295	Unspecified injury of thorax	S066	191	Traumatic subarachnoid haemorrhage

Appendix 9: SIOI LTTL and HTTL injury diagnoses, by age group for car occupant injuries

Non-serious			**Serious**		
Diagnosis code	Freq	Diagnosis description	Diagnosis code	Freq	Diagnosis description
< 25 years					
S134	404	Sprain or strain of cervical spine	S0601	172	Loss of consciousness unspecified duration
S099	335	Unspecified injury of head	S723	153	Fracture of shaft of femur
S0600	274	Concussion	S065	149	Traumatic subdural haemorrhage
S399	265	Unspecified injury of abdomen, lower back and pelvis	S010	133	Open would of scalp
S0602	255	Loss of consciousness, brief duration (<30min)	S066	126	Traumatic subarachnoid haemorrhage
25-34 years					
S134	220	Sprain or strain of cervical spine	S723	58	Fracture of shaft of femur
S399	164	Unspecified injury of abdomen, lower back and pelvis	S0601	57	Loss of consciousness unspecified duration
S199	119	Unspecified injury of neck	S010	53	Open would of scalp
S202	113	Contusion of thorax	S066	51	Traumatic subarachnoid haemorrhage
S0600	99		S0602	37	Loss of consciousness, brief duration (<30min)
35-44 years					
S134	192	Sprain or strain of cervical spine	S0601	33	Loss of consciousness unspecified duration
S202	106	Contusion of thorax	S222	31	Fracture of sternum
S199	89	Unspecified injury of neck	S066	30	Traumatic subarachnoid haemorrhage

S399	74	Unspecified injury of abdomen, lower back and pelvis	S065	29	Traumatic subdural haemorrhage
S099	65	Unspecified injury of head	S010	28	Open would of scalp
> 45 years					
S202	527	Contusion of thorax	S222	325	Fracture of sternum
S222	385	Fracture of sternum	S121	179	Fracture of second cervical vertebra
S134	315	Sprain or strain of cervical spine	S065	139	Traumatic subdural haemorrhage
S299	264	Unspecified injury of thorax	S2244	134	Multiple rib fractures involving four or more ribs
S199	174	Unspecified injury of neck	S7211	94	Fracture of intertrochanteric section of femur

Appendix 10: SIOI LTTL and HTTL injury diagnoses, by age group for motorbike injuries

Non-serious			**Serious**		
Diagnosis code	Freq	Diagnosis description	Diagnosis code	Freq	Diagnosis description
< 25 years					
S810	91	Open wound of knee	S723	41	Fracture of lateral malleolus
S8218	84	Other fracture of upper end of tibia	S0601	39	Loss of consciousness unspecified duration
S723	74	Fracture of shaft of femur	S0602	23	Loss of consciousness, brief duration (<30min)
S8221	72	Fracture of shaft of tibia with fracture of fibula	S810	21	Open wound of knee
S526	54	Fracture of lower end of ulna and radius	S065	19	Traumatic subdural haemorrhage
25-34 years					
S8218	58	Other fracture of upper end of tibia	S723	22	Fracture of lateral malleolus
S8221	53	Fracture of shaft of tibia with fracture of fibula	S066	13	Traumatic subarachnoid haemorrhage
S810	49	Open wound of knee	S0602	11	Loss of consciousness, brief duration (<30min)
S4202	43	Fracture of shaft of the clavicle	S0601	10	Loss of consciousness unspecified duration
S826	31	Fracture of lateral malleolus	S065	10	Traumatic subdural haemorrhage
35-44 years					

S8218	58	Other fracture of upper end of tibia	S723	33	Fracture of lateral malleolus
S8221	58	Fracture of shaft of tibia with fracture of fibula	S270	18	Traumatic pneumothorax
S4202	41	Fracture of shaft of the clavicle	S2244	17	Multiple rib fractures involving four or more ribs
S826	33	Fracture of lateral malleolus	S066	15	Traumatic subarachnoid haemorrhage
S923	33	Fracture of metatarsal bone	S8221	15	Fracture of shaft of tibia - open
> 45 years					
S8221	106	Fracture of shaft of tibia with fracture of fibula	S2244	70	Multiple rib fractures involving four or more ribs
S826	99	Fracture of lateral malleolus	S270	61	Traumatic pneumothorax
S8218	89	Other fracture of upper end of tibia	S4202	37	Fracture of shaft of the clavicle
S4202	64	Fracture of shaft of the clavicle	S066	32	Traumatic subarachnoid haemorrhage
S8281	47	Fracture of other parts of lower leg - open	S723	32	Fracture of lateral malleolus