MONASH University

ACCIDENT RESEARCH CENTRE

ENHANCED CRASH INVESTIGATION STUDY (ECIS)

SPEED, CRASH RISK AND INJURY SEVERITY, ECIS REPORT 2.

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16 DECEMBER 2022

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MONASH University

FOREWORD

Through sponsorship and support from the Victorian Transport Accident Commission (TAC), the Monash University Accident Research Centre (MUARC) with leading local and international partners established the Enhanced Crash Investigation Study (ECIS).

The ECIS program was designed to provide insight into how serious injury crashes occur and then using this information, identify measures that would be effective in preventing occupants of vehicles being seriously injured in the event of a crash.

This report is the second in the ECIS Report series. This report examines the role of vehicle speed in crash occurrence and injury severity. The analysis uses the data collected in the ECIS Case Arm and the ECIS Control Arm, as well as detailed crash reconstructions where selected pre-crash inputs, such as travel speed, are modified so that the theoretical impact of these measures on crash outcomes can be demonstrated.

This report seeks to:

- Document the relationship between the speed limit and travel speed.
- Document the relationship between travel speed and hospitalisation-severity crash risk.
- Document the relationship between travel speed and vehicle speed at impact.
- Document the frequency of pre-crash steering and braking avoidance actions.
- Document the relationship between crash impact speed and injury severity.
- Assess the potential benefits of lower impact speeds on injury severity outcomes.
- Illustrate the potential benefits of reduced travel speed, speed limit compliance and reduced impact speed on crash and injury severity outcomes using a case series approach.

Addressing these areas of focus will provide a comprehensive examination of the role of vehicle speed and its impact on road safety. It is expected that the insight gained from this analysis will serve as an invaluable input into decisions aimed at eliminating serious injury on the Victorian road transport system.

Keywords: vision zero, safe system, crash, travel speed, impact speed, hospitalisation, serious injury, abbreviated injury scale, MAIS 3+, road safety, crash risk, crash avoidance, braking, crash reconstruction, speed reduction scenarios.

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DEDICATION

On 11 January 2021, our much-loved colleague Professor H. Clay Gabler III passed away in Virginia, United States. Clay touched our lives in many great ways, always demonstrating great warmth, compassion, patience, and humour. Clay was an intellectual giant and an inspiration to us. He will be greatly missed.

Professor H. Clay Gabler

B.S. (Nuclear Engineering, *Virginia*), M.E. (Nuclear Engineering, *Virginia),* M.A. (Mechanical and Aerospace Engineering, *Princeton)*, PhD (*Princeton),* FAIMBE, FAAAM, FSAE.

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ACKNOWLEDGMENTS

The ECIS Investigators express their sincere gratitude to the injured drivers and families who participated in the study. We certainly appreciate that the experience of being involved in a crash and admitted to hospital is extremely traumatic, overwhelming and is a period of great uncertainty. We are eternally grateful that you consented to participate in the ECIS program.

It is through this selfless participation that this report and the ECIS Report Series are possible. The goal of course is that the insight gained and documented here on the causes and consequences of serious injury crashes finds its way into improved road safety policy and practice, including improvements in the design of cars and roads.

Our commitment to you is to work hard on ensuring that the findings of the ECIS program are used to create the safest road transport system possible. Our goal is to eliminate the risk of serious injury in crashes and to ensure every person gets home safely, every time. The lessons we have learned from each and every crash in the ECIS program will make this possible.

A project of this magnitude and scope is only possible due to a large number of people making invaluable contributions. Organisations and key individuals are noted below.

Transport Accident Commission (TAC)

MUARC acknowledges the funding and logistical support provided by the Victorian Transport Accident Commission (TAC). In particular, we wish to thank the TAC Board and Mr Joe Calafiore (CEO) for supporting the study from the beginning.

At the TAC, we also wish to thank Mr Michael Nieuwesteeg (Director Road Safety Programs & Policy; ECIS Project Manager) and Ms Samantha Cockfield (Senior Manager, Road Safety) for their unwavering support and assistance throughout the project. We also wish to acknowledge the role of Mr John Thompson (TAC) for his role in the formative stages of the program.

We would also like to acknowledge the support of Jacinta Evans for assistance with the ECIS Control Arm of the program. Particular thanks must also be extended to Renee Schuster and Jodi Page-Smith for assistance with the ECIS Control Arm and insight into the TAC Claims data, and to Samantha Buckis (nee Collins) for inputs on data collection measures.

The contributions of Paulette Ziekemijjer (Manager, Research, Insights and Evaluation, Road Safety), Antonietta Cavallo, David Healy, Peter Milne, and Chris Jurewicz to the report are gratefully acknowledged.

The Alfred Hospital and the Royal Melbourne Hospital

The ECIS team is grateful to Professor Russell Gruen, Professor Mark Fitzgerald (The Alfred, National Trauma Research Institute) and Professor Rodney Judson (Royal Melbourne Hospital) for facilitating the study at their respective hospitals.

Appreciation is extended to Kellie Liersch, Kellie Gumm and Mary-Lou Greer at the Royal Melbourne Hospital and Kim Williams, Roy Chow and Kevin Mittelstaedt (The Alfred) for day-to-day assistance as well as logistics and research ethics processes and approvals.

We are grateful to the medical, nursing, and allied health staff at both The Alfred and the Royal Melbourne Hospital for assistance and support throughout the study.

Victoria Police and Emergency Services

We are grateful to various members of Victoria Police for assistance throughout the project. In particular, we wish to thank Detective Inspector Stuart McGregor, Inspector Cath Wilkins, Inspector Joseph Adams, Lisa Brodie, Kerry Cleaver, and Dr David Ballek.

We wish to thank the Victorian State Emergency Services (SES), Ambulance Victoria (AV) and the Country Fire Authority (CFA) who provided advice and assistance during the course of the study.

Tow-truck operators

The ECIS Team acknowledges the assistance of the many tow-operators and car repair services that permitted access to their premises to inspect damaged vehicles.

Participants of Expert Panels, Regional Panels and Safe System Forums

Throughout the study, many members of local government, VicRoads, Victoria Police, the SES, Ambulance Victoria, the TAC, the Department of Health and Human Services, the Department of Justice and Regulation and members of local communities involved in road safety action groups participated in Expert and Regional Panels. Their knowledge and insights of community road safety were invaluable.

We also thank participants of the ECIS Safe System Workshops, including Professor Claes Tingvall, Dr Anders Lie and Dr Johan Strandroth.

At Monash University

We acknowledge the support and contribution of Professor Stuart Newstead (Director, MUARC) and former Directors Professor Judith Charlton, Professor Mark Stevenson, Professor Rod McClure, and Professor Lesley Day in the conduct of the program.

We also acknowledge the assistance of Mr Ron Smith, Chief Operating Officer (MUARC), for assistance with the financial administration of the project, as well as Mrs Lesley Rees, Operations Co-ordinator (MUARC) with event support, HR support and a host of other matters.

In addition, we wish to acknowledge the contribution of the team at the Monash University Research and Revenues Accounting Services, in particular, Intan Lehman, Mohit Bassi, and Joanne Chen for finance support and purchasing.

We also thank Ms Sarah Hughes, Ms Sarah Hills, and Ms Renee Benetti for HR Support throughout the program.

On a personal note, Associate Professor Michael Fitzharris thanks Mr Richard Jones (Oxford Consulting), Dr Karen Choong (Hawthorn Medical) and Dr Logan Bittinger (Melbourne Heart Care) for their support and assistance.

The ECIS Team

The ECIS team involved many individuals across numerous roles. All who played a vital role in the conduct of the study are listed here.

ECIS Investigators

- Associate Professor Michael P. Fitzharris
- Dr Bruce Corben (Corben Consulting)
- Professor Mike G. Lenné

ECIS International Investigators

- Associate Professor Diana M. Bowman, Arizona State University, USA
- Professor Hampton C. Gabler, Virginia Tech, USA
- Professor Andrew Morris, Loughborough University, UK
- Professor Claes Tingvall, ÅF Pöyry AB (AFRY), Sweden

ECIS Hospital Investigators

- Professor Mark Fitzgerald, The Alfred Hospital
- Professor Rodney Judson, The Royal Melbourne Hospital

ECIS Project Managers

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- Tandy Pok Arundell

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- Nicola Elliott
- Kathryn Joseph
- Marnie Reilly
- Emily Robertson
- Karen Vlok
- Kim Woolley

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- Rai Curry
- Allen Guenther
- Ron Laemmle
- Anna Magennis
- Geoff Rayner

ECIS Crash Reconstruction Team

- Tandy Pok Arundell
- Tom Behrendt
- Anna Magennis
- James McCutcheon
- Sujanie Peiris
- Natalie Seeto

ECIS Control Arm Team

- Robin Jackel
- Lindsay Lorrain

ECIS Data and Administration Team

- Caitlin Bishop
- Debra Judd
- Revathi N. Krishna
- Chloe Lacey
- Daniel Machell
- Hayley McDonald
- Russell Phoung
- Paul Ribas

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EXECUTIVE SUMMARY

THE ENHANCED CRASH INVESTIGATION STUDY

The ECIS program had two objectives:

1) To provide the TAC with insight into how serious injury crashes occur.
2) To identify crash prevention measures as well as measures that would be effective in preventing occupants of vehicles being seriously injured once a crash occurs.

This report addresses the first objective and achieves this through the forensic study of hospitalisation crashes. The findings of the ECIS program are presented across four reports. This report is the second in the series.

REPORT OBJECTIVES

This report examined the role that speed plays in driving crash risk and in shaping injury severity. The report set out to address five questions, these being:

1. What is the relationship between the speed limit and travel speed?
2. What is the relationship between travel speed and the risk of involvement in a crash that results in one or more involved drivers being hospitalised (referred to as *hospitalisation-severity crash risk)*?
3. What is the relationship between the travel speed of a vehicle and the speed of the (same) vehicle at impact, the frequency of pre-crash avoidance actions and the effect, if any, of these actions on vehicle speed at the point of impact?
4. What is the relationship between impact speed and injury severity?
5. What is the injury reduction benefit of lower impact speeds?

In addition to these five questions, this report sought to illustrate the potential benefits of reduced travel speed, speed limit compliance and reduced impact speed on crash and injury severity outcomes using a case series approach.

Addressing these questions represents a comprehensive examination of the role that vehicle speed plays in regulating the safety of the road transport system. This understanding is central to *Vision Zero* and the *Safe System* approach.

It is expected that by addressing these key questions, the findings will serve as an invaluable input into decisions aimed at eliminating serious injury on the Victorian road transport system. Further, it is hoped that the findings can be used to inform the public debate on the role of speed in shaping the safety of Victorian roads. The principal findings are as follows.

PRINCIPAL FINDINGS

THE ROLE OF THE SPEED LIMIT IN DETERMINING TRAVEL SPEED

The first step in examining the role of speed as a regulator of the safety of the road transport system was to determine the relationship between the speed limit and travel speed chosen by drivers. Driver speed choice was examined through the correlation between speed limits and travel speed. Using travel speed data from 2,180 drivers, a high correlation was found ($r = 0.738$, $p < 0.001$). The mean and median speed choice of drivers tracked closely to the speed limit across all speed zones, with data presented for speed limits ranging from 50 km/h to 110 km/h. This relationship can be seen in Figure E.1.

The data also showed that 15.0% of drivers were exceeding the speed limit by 3 km/h or more. However, differences were evident across speed limit zones, with 38.1% of drivers exceeding the speed limit by 3 km/h or more in 70 km/h zones. In contrast, 8.1% of drivers in 100 km/h zones were exceeding the speed limit by 3 km/h or more. The proportion of drivers exceeding the speed limit by 5 km/h or more was 10.3% with differences across speed limit zones evident.

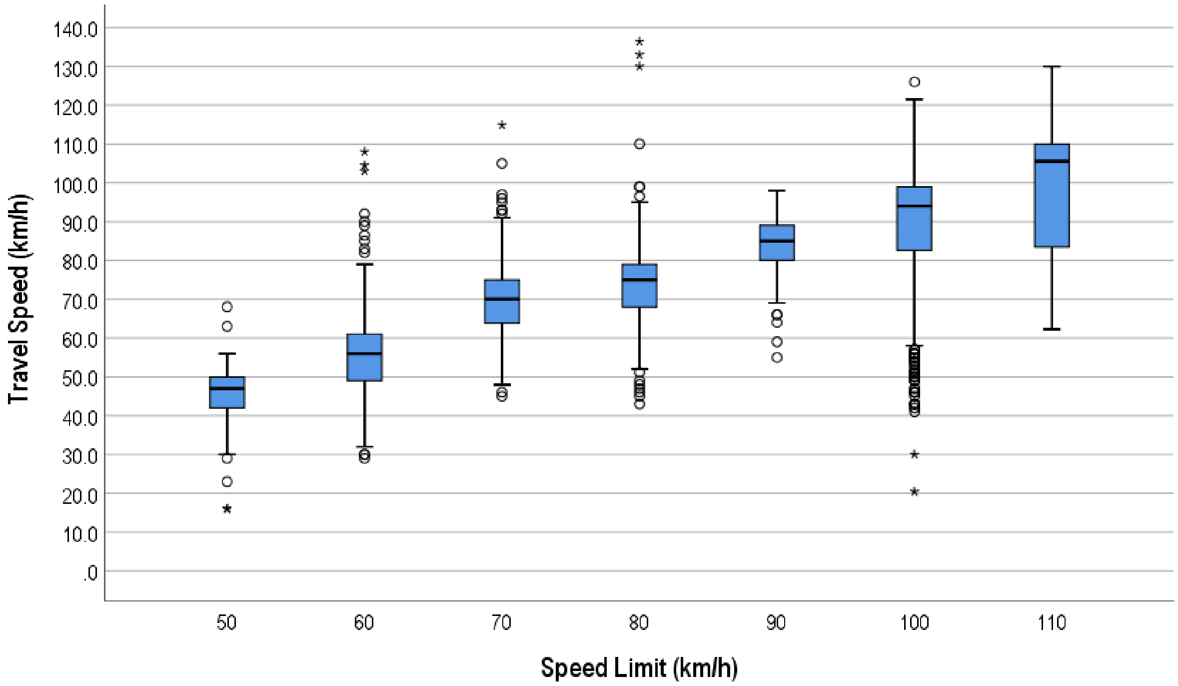


FIGURE E.1 CORRELATION BETWEEN TRAVEL SPEED AND THE SPEED LIMIT[1]

This analysis represents the first link in the chain of the role of speed and the importance of speed limits in shaping driver behaviour. The findings demonstrate a high degree of driver compliance, this being important from a number of perspectives, in particular, that speed limit changes would be highly likely to result in a shift in driver behaviour. Nonetheless, that a proportion of drivers fail to obey the speed limits highlights a role for continued enforcement and opens up the prospect of active vehicle safety systems, such as Intelligent Speed Assist (ISA), playing a role in ensuring safe driver behaviour.

PRINCIPAL FINDINGS	
1	Driver travel speed was highly correlated with the speed limit (r = 0.738). The mean and median travel speed reflected the speed limit across all speed zones.
2	The proportion of drivers exceeding the speed limit by 3 km/h or more was 15.0% and 10.3% of drivers were exceeding the speed limit by 5 km/h or more. There were differences in the proportion of drivers exceeding the speed limit across speed limit zones, with the lowest levels of non-compliance being in 80 km/h zones and higher. The highest level of non-compliance was seen in 70 km/h zones (≥ 5 km/h: 28.4%), followed by 60 km/h zones (≥ 5 km/h: 14.6%), and 50 km/h zones (≥ 5 km/h: 8.5%).

THE RELATIONSHIP BETWEEN TRAVEL SPEED AND HOSPITALISATION-SEVERITY CRASH RISK AND THE BENEFITS OF ELIMINATING SPEEDING

The relationship between travel speed and the risk of being involved in a crash is a fundamental question in road safety. The ECIS program was designed to address this question. Specifically, two questions were of interest:

1. What is the relationship between travel speed and crash risk? As the ECIS program was focussed on hospitalised drivers, the crash risk examined here is correctly stated to be the risk of being involved in a crash where one or more involved drivers was hospitalised. For the purposes of brevity, this is referred to as 'crash risk' or 'hospitalisation-severity crash risk'.
2. What are the crash reduction benefits of 100% driver compliance with the speed limit?

The relationship between travel speed and crash risk for hospitalised drivers was examined using a Case-Control analysis. This involved statistically comparing the travel speed of drivers who crashed (i.e., Case drivers) with the travel speed of drivers measured at the same location but who did not crash (i.e., Control

1 Box plot shows the following: median (horizontal line) with the box itself bounded by the 25th percentile (Q1) and the 75% percentile (Q3); this is the interquartile range (IQR). The lower capped lines give the 'minimum' (= Q1 - 1.5*IQR) while the upper capped line is the 'maximum' (= Q3 + 1.5*IQR). Outliers are shown by circles (o) and extremes are shown by Asterix (*).

drivers). After excluding crashes and drivers where alcohol and/or drugs were present and including driver age and driver sex in the statistical models, a robust relationship was found between travel speed and crash risk for crashes that involved a driver requiring admission to a major trauma centre for the treatment of injuries.

In the estimation of crash risk, travel speed was used in its continuous, raw, form. Travel speed was modelled as a continuous variable using deviation from the speed limit (i.e., free travel speed – speed limit), thereby enabling the crash risk associated with travelling below/above the speed limit to be estimated.

The analysis demonstrated that travel speed was associated with *crash risk* and that this association was statistically significant ($p < 0.001$). Driving in excess of the speed limit was associated with a higher crash risk. Conversely, travelling below the speed limit had a protective effect and was associated with a lower crash risk. This was the case for all crashes, as well as when the analysis was limited to Lane Departure crashes and Across Path crashes (Table E.1, Figure E.2).

For instance, across all crashes, for every 1 km/h travelling above the speed limit, the relative risk of being involved in a hospitalisation-severity crash increases by an estimated 7.6%, adjusted for driver age and driver sex (RR: 1.08, 95% CI: 1.06 – 1.10, $p < 0.001$).

For low level speeding – defined as driving 3 km/h above the speed limit – the increased crash risk was estimated to be 25%; the 95% confidence intervals estimate that this increased risk could be as low as 18% or as high as 32% (RR: 1.25, 95% CI: 1.18 – 1.32). Drivers travelling 5 km/h above the speed limit had an estimated 1.44 times higher crash risk than that of drivers travelling at the speed limit; this equates to a 44.4% increased crash risk (95% CI Range = +31.1% to +59.4%; RR: 1.44, 95% CI: 1.31–1.59). Hence, it can be stated that driving at 5 km/h above the speed limit was associated with a 44.4% increase in crash risk compared to driving the speed limit.

For drivers travelling 10 km/h above the speed limit the crash risk was estimated to be more than double (i.e., twice) that of drivers travelling at the speed limit (+108.5%; RR: 2.09, 95% CI: 1.72–2.53). Driving 15 km/h above the speed limit was associated was associated with a crash risk triple that of drivers travelling at the speed limit (+201.1%; RR: 3.01, 95% CI: 2.26–4.01).

The protective effect of driving below the speed limit was also evident with, for example, drivers travelling 5 km/h below the speed limit having a crash risk 0.69 times that of drivers travelling at the speed limit, translating to an estimated 30.8% lower risk of being involved in a hospitalisation severity crash (RR: 0.69, 95% CI: 0.63 – 0.76). The protective effect of travelling below the speed limit was greater with travel speeds further below the speed limit. For instance, the crash involvement risk was 52.0% lower for drivers travelling 10 km/h below the speed limit (RR: 0.48, 95% CI: 0.40–0.58) and 66.8% lower for drivers travelling 15 km/h below the speed limit (RR: 0.33, 95% CI: 0.25–0.44).

The analysis presented in the body of the report also highlights the increased crash risk of young drivers (18 – 25 years of age), older drivers (76+ years of age) and male drivers.

The analysis examined the crash reduction benefit that could be achieved by ensuring 100% compliance with current speed limits. The calculation of the Population Attributable Fraction (PAF) estimated that 7.9% reduction in the number of hospitalisation crashes could be achieved by eliminating speeding behaviour.

TABLE E.1 CRASH INVOLVEMENT RISK RATIO (RR) AND 95% CONFIDENCE INTERVALS RELATIVE TO DRIVING AT THE SPEED LIMIT, ADJUSTED FOR DRIVER AGE, DRIVER SEX

TRAVEL SPEED RELATIVE TO DRIVING AT THE SPEED LIMIT (KM/H)	RR	95% CI	
		LOWER	UPPER
-15	0.33	0.25	0.44
-10	0.48	0.40	0.58
-5	0.69	0.63	0.76
0	1.00	-	-
5	1.44	1.31	1.59
10	2.09	1.72	2.53
15	3.01	2.26	4.01

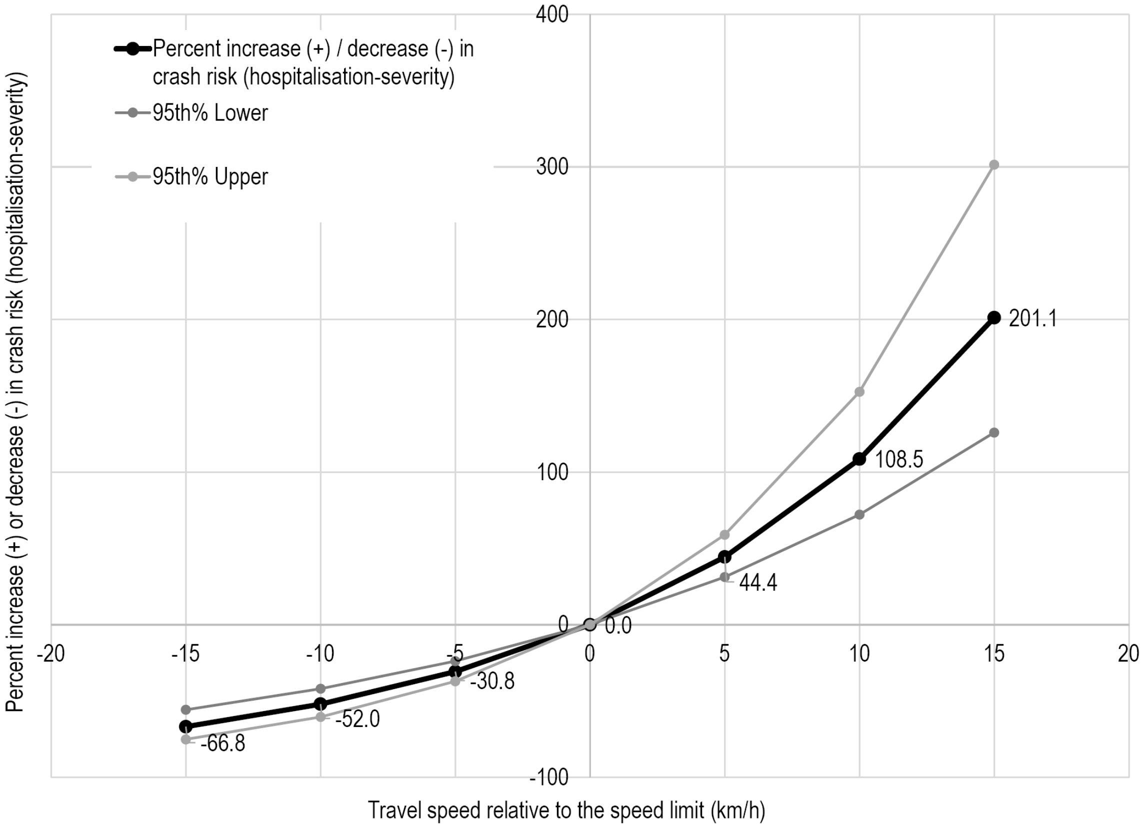


FIGURE E.2 INCREASE (+) / DECREASE (-) IN HOSPITALISATION-SEVERITY CRASH RISK RELATIVE TO DRIVING AT THE SPEED LIMIT, ADJUSTED FOR DRIVER AGE AND SEX

PRINCIPAL FINDINGS	
3	Travel speed was associated with the risk of being involved in a crash where one (or more) involved driver required hospitalisation for injuries sustained. Driving in excess of the speed limit was associated with a higher crash risk while conversely travelling below the speed limit had a protective effect and was associated with a lower crash risk. This relationship was seen individually in Lane Departure crashes and Across Path crashes, as well as in all crashes combined. By way of example, drivers travelling 5 km/h above the speed limit had an estimated 1.44 times higher crash risk than that of drivers travelling at the speed limit. In percentage terms, this is interpreted as driving at 5 km/h above the speed limit was associated with a 44.4% increase in crash risk compared to driving at the speed limit. Travelling 5 km/h below the speed limit was associated with an estimated 30.8% lower crash risk than drivers travelling at the speed limit.
4	Young drivers (18 – 25 years of age), older drivers (76+ years of age) and male drivers had a higher crash involvement risk than other aged drivers and females.
5	Nearly one-fifth of crash-involved drivers were exceeding the speed limit prior to the crash (18.6%), with this being higher for drivers involved in Lane Departure crashes (27.0%) than for Across Path crashes (11.4%). The proportion of drivers exceeding the speed limit was higher among drivers who were involved in a crash than those who were not. That the vast majority of drivers were complying with the speed limit yet were seriously injured underscores the inadequacy of current speed limits in protecting drivers in the event of a crash. This points to the need to better match speed limits with the available road infrastructure whilst being cognisant of the level of protection afforded by vehicles. This point was addressed in detail in *ECIS Report 1*.
6	The elimination of speeding behaviour using speed limits as currently set would result in a 7.9% reduction in the number of hospitalisation crashes. This calculation was statistically adjusted for driver age and driver sex and excludes crashes where an involved driver had consumed alcohol and/or had used illicit drugs (AOD). Hence, this 7.9% reduction estimate in hospitalisation crashes does not include crash-involved drivers who had used AOD and who were exceeding the speed limit.

THE LINK BETWEEN TRAVEL SPEED, VEHICLE SPEED AT IMPACT AND PRE-CRASH AVOIDANCE ACTIONS

Having linked travel speed with the speed limit and demonstrated the relationship between travel speed and the risk of being involved in a hospitalisation-severity crash, the next step in understanding the regulating role of speed in the road transport system is the relationship between travel speed and the speed of vehicles at impact. Following this, there are two related questions:

1. What is the relationship between travel speed and the speed of vehicles at impact?
2. What proportion of drivers engaged in pre-crash avoidance behaviours and what was the effect, if any, on the relationship between travel speed and vehicle speed at impact?

Using the data derived from the crash reconstruction process, 54.5% of drivers involved in Lane Departure crashes and Across Path crashes braked prior to the crash, however braking was more common in higher speed limit zones. Steering avoidance manoeuvres were more common among drivers who braked (45.7%) than those who did not (10.9%). Differences in pre-crash braking and steering actions were evident across Lane Departure crashes, Across Path crashes and Rear Impact crashes.

Vehicle speed at impact was correlated with travel speed, as expected; however, this was modified by driver braking (Table E.2). This is seen by the magnitude of the correlation coefficient (r) being larger where drivers did not brake ($r = 0.86$, $p < 0.001$) than where braking was applied ($r = 0.67$, $p < 0.001$); this result simply reflects the effect of braking in reducing vehicle speed.

TABLE E.2 CORRELATION BETWEEN TRAVEL SPEED AND SPEED AT IMPACT. BY BRAKING STATUS

	DRIVER BRAKED PRE-CRASH	NO BRAKING PRE-CRASH
CRASH TYPE	R	R
All	0.67** (n = 265)	0.86** (n = 220)
Lane Departure	0.57** (n = 157)	0.73** (n = 70)
Across Path	0.79** (n = 87)	0.83** (n = 117)
Rear Impact	0.84** (n = 21)	0.93** (n = 33)

** p < 0.001.

The principal finding is the robust correlation between travel speed and vehicle speed at impact. Per *ECIS Report 1*, the time under braking was short, resulting in there being insufficient time to avoid the crash. Steering avoidance actions were also insufficient in preventing these crashes. Combined with the previous finding that speed choice (i.e., travel speed) is driven by the speed limit, this finding provides a key link between the speed limit and impact speed.

PRINCIPAL FINDINGS	
7	Vehicle speed at impact was highly correlated with travel speed, the strength of the correlation being modified by the presence of braking.
8	Approximately half (54.5%) of all drivers braked immediately prior to the crash, 'wiping-off' slightly less than one-third (-30.9%) of travel speed.

THE RELATIONSHIP BETWEEN IMPACT SPEED AND SERIOUS INJURY, AND THE BENEFITS OF LOWER IMPACT SPEED IN CRASHES

The relationship between impact speed and MAIS 3+ (serious) injuries was examined. This enabled the assessment of the potential benefits of reduced travel speed and impact speed on crash and injury severity.

The analysis demonstrated a direct relationship between impact speed and MAIS 3+ injury. As shown in Figure E.3, the probability of a driver sustaining an MAIS 3+ injury increases with impact speed, as expected. This was seen in both frontal and side impact crashes.

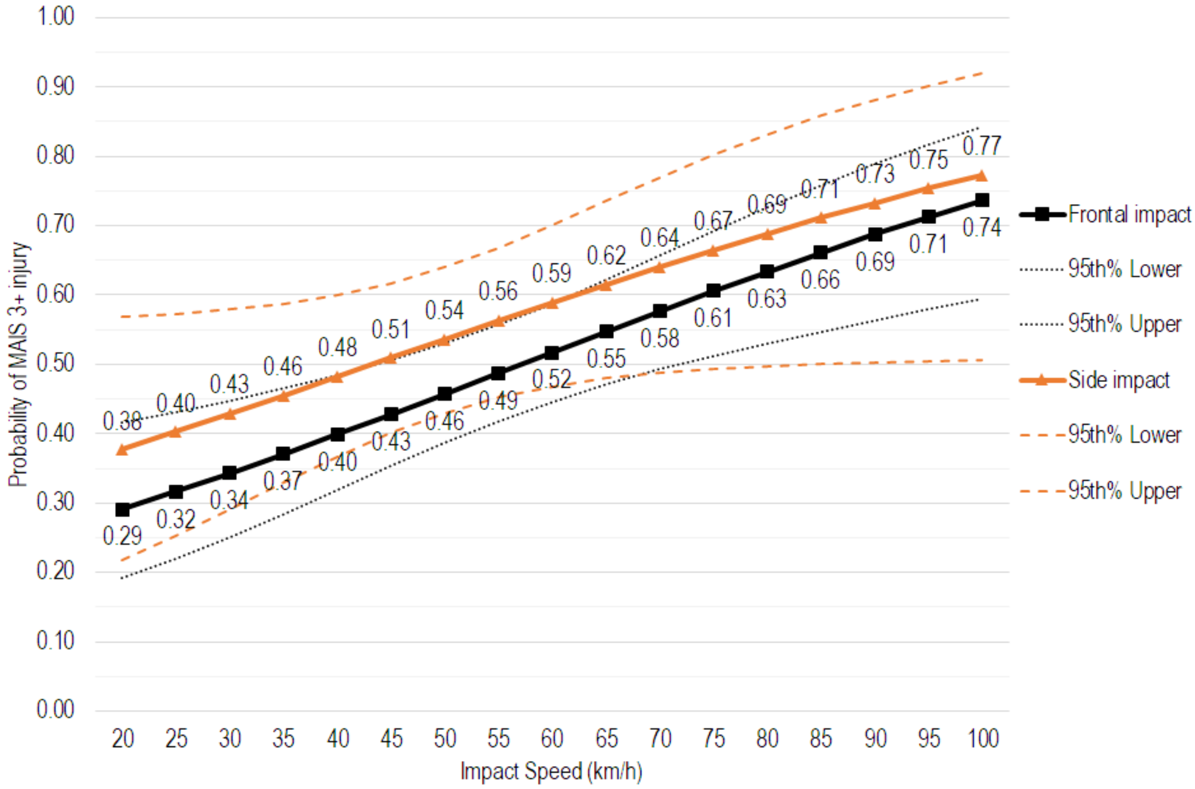


FIGURE E.3 PROBABILITY (95% CONFIDENCE INTERVALS) OF AN ECIS DRIVER SUSTAINING AN MAIS 3+ INJURY IN FRONTAL IMPACT AND SIDE IMPACT CRASHES BY IMPACT SPEED, GIVEN ALL DRIVERS WERE HOSPITALISED

This relationship was used as the basis for assessing the safety benefit associated with a 5 km/h reduction in impact speed and a 10 km/h reduction in impact speed. The analysis indicated that a 6.3% reduction in the percentage of hospitalised drivers sustaining MAIS 3+ injuries involved in frontal and side impact crashes could be achieved through a 5 km/h reduction in impact speed (Figure E.4). This benefit increases to a 12.2% reduction given a 10 km/h reduction in impact speed. The benefit was higher for frontal impact crashes than for side impact crashes.

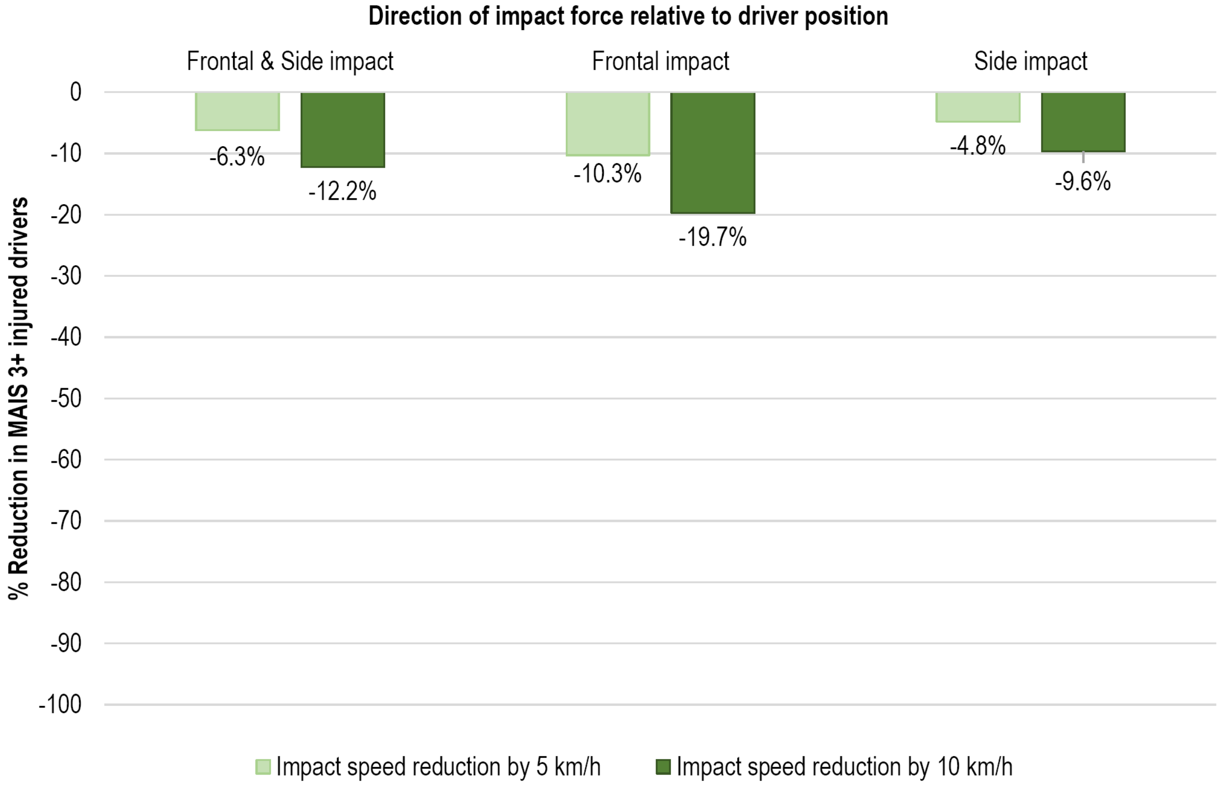


FIGURE E.4 EXPECTED REDUCTION IN THE PERCENT OF HOSPITALISED DRIVERS WITH MAIS 3+ INJURIES GIVEN A 5 KM/H AND 10 KM/H HYPOTHETICAL REDUCTION IN IMPACT SPEED

It was stated in the report that these reductions could be achieved on a population-level more rapidly by reducing speed limits—supported by sustained enforcement and public education—given the time lag between widespread adoption and penetration of key vehicle safety systems and the upgrade of existing road infrastructure to the required *Safe Roads* standard.

PRINCIPAL FINDINGS

9 Impact speed was associated with sustaining serious MAIS 3+ injuries, with injury risk increasing with higher impact speeds. A 6.3% reduction in hospitalised drivers sustaining MAIS 3+ injuries in frontal and side impact crashes could be achieved through a 5 km/h reduction in impact speed. This benefit increases to a 12.2% reduction given a 10 km/h reduction in impact speed.

ILLUSTRATING THE EFFECT OF SPEED LIMIT CHANGES ON CRASH OUTCOMES USING CRASH SIMULATION MODELLING: A CASE SERIES APPROACH

To illustrate the practical effect of speed limit reductions, a series of 'what if' alternative scenarios were modelled using crash reconstruction computer software. Speed reduction measures of -10 km/h, - 20 km/h and -30 km/h were applied, depending on the speed limit, to a selection of 10 ECIS crashes. In each case, speed compliance was assumed given the behaviour of the crash-involved drivers in the actual crash, or was forced if a driver was not complying with the speed limit in the actual crash scenario.

Alternative speed limit and compliance scenarios were applied to three intersection crashes, three single-vehicle run-off-road crashes, three head-on crashes, and one rear impact crash. This built on the peer reviewed research that examined the benefits of speed limit changes and infrastructure measures on the outcome of a high speed rural Across Path crash.[2]

The analysis demonstrated that complete crash avoidance was achieved in 6 of the 24 alternative speed limit scenarios modelled (25%) and in 5 of the 10 crashes (50%) examined depending on the speed limit reduction scenario.

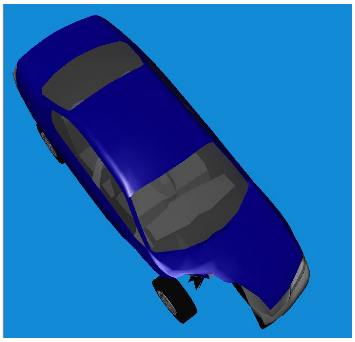
2 Peiris S, Corben B, Nieuwesteeg M, Gabler HC, Morris A, Bowman D, et al. Evaluation of alternative intersection treatments at rural crossroads using simulation software. Traffic Injury Prevention. 2018;19(sup2):S1-S7.

For scenarios where crashes would continue to occur, the lower travel speed was associated with lower impact speeds; this was the case in 16 alternative crash scenarios. As a consequence of the lower impact speeds, the involved driver(s) and other vehicle occupants (where applicable) would be exposed to lower levels of mechanical and inertial forces from which injury results. Given the established relationship between impact speed and the probability of sustaining MAIS 3+ injury, the injury reduction benefit of these reduced speed scenarios would be significant.

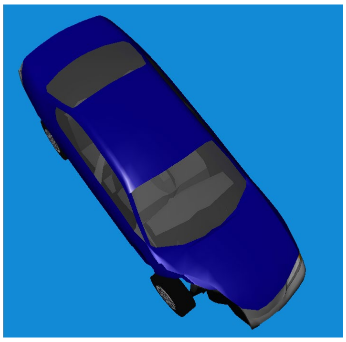
By way of example, Figure E.5 presents a graphical illustration of the change in the damage profile of vehicles involved in a frontal-offset crash on a road with a 100 km/h speed limit and the change associated with lower speed limits. As is evident, the change in vehicle deformation was substantial, particularly when the speed limit was reduced from 100 km/h to 80 km/h. In the scenario where the speed limit was reduced to 70 km/h, the crash could be avoided due to driver braking.

A-VEHICLE | B-VEHICLE

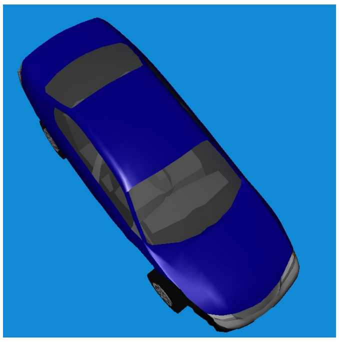
BASELINE CRASH SCENARIO (100 KM/H SPEED LIMIT)

ALTERNATIVE SCENARIO (1): SPEED LIMIT REDUCED TO 90 KM/H

ALTERNATIVE SCENARIO (1): SPEED LIMIT REDUCED TO 80 KM/H

ALTERNATIVE SCENARIO (1): SPEED LIMIT REDUCED TO 70 KM/H

IMPACT AVOIDED | **IMPACT AVOIDED**

FIGURE E.5 CRASH RECONSTRUCTION REPRESENTATION OF IMPACT DAMAGE

PRINCIPAL FINDINGS	
10	Applying alternative speed limit scenarios to 10 real-world crashes using crash reconstruction, it was found that half of the crashes would be avoided where lower travel speeds reflect lower speed limits, assuming all other factors stayed constant. In scenarios where crashes still occurred the impact speed and associated crash forces and vehicle deformation were estimated to be lower, directly translating to a lower risk of serious injury.

The case series demonstrates the positive benefit of speed limit reductions and associated driver compliance in reducing the occurrence of crashes and the severity of those that continue to occur. On this latter point, and where crashes continue to occur, the road trauma benefit is driven by lower impact speeds. The case series highlights an important point: while any reduction in speed limits will have a positive benefit on road safety, small speed limit reductions were largely insufficient to bring the impact speed of the crash within the safety envelope of the vehicle; this was especially the case in 90 km/h and 100 km/h speed zones. Given the predictability of crashes and the serious injury outcomes, the critical importance of setting speed limits appropriately cannot be overstated.

The case series serves to highlight the critical links between the speed limit, driver speed choice, impact speed and injury severity. In doing so, the road safety benefits of lower, and appropriately set, speed limits were evident. As stated in this report and in *ECIS Report 1*, speed limits need to be guided by best practice, cognisant of the inherent safety of available road infrastructure and the safety provided by vehicles to occupants in the event of a crash. While the setting of speed limits to appropriate levels is an essential step for reductions in serious injury to be achieved in Victoria, for the full trauma reduction savings of these lower speed limits to be realised, full compliance with these speed limits must be achieved. This level of compliance can be achieved through a combination of enforcement, the widespread adoption of advanced active vehicle safety systems, the promotion of driver compliance through road design, and the energy management attributes of system-based road infrastructure solutions.

ASSUMPTIONS, LIMITATIONS AND APPLICATION OF FINDINGS

The analysis and findings presented here are subject to a number of assumptions and limitations. These are stated, as appropriate, within each chapter.

As outlined in detail in *ECIS Report 1*, the ECIS program was designed to be a study of hospitalised drivers subsequent to involvement in a crash. It is therefore important that the findings of this report are viewed and communicated with this in mind. Specifically, the findings are most applicable to crashes involving passenger vehicles where at least one driver was hospitalised, noting that the ECIS sample was biased towards the more serious end of the road trauma spectrum with close to half (47%) of all enrolled ECIS drivers sustaining MAIS 3+ ('serious') injuries (see *ECIS Report 1* for detail).

CONCLUDING COMMENT

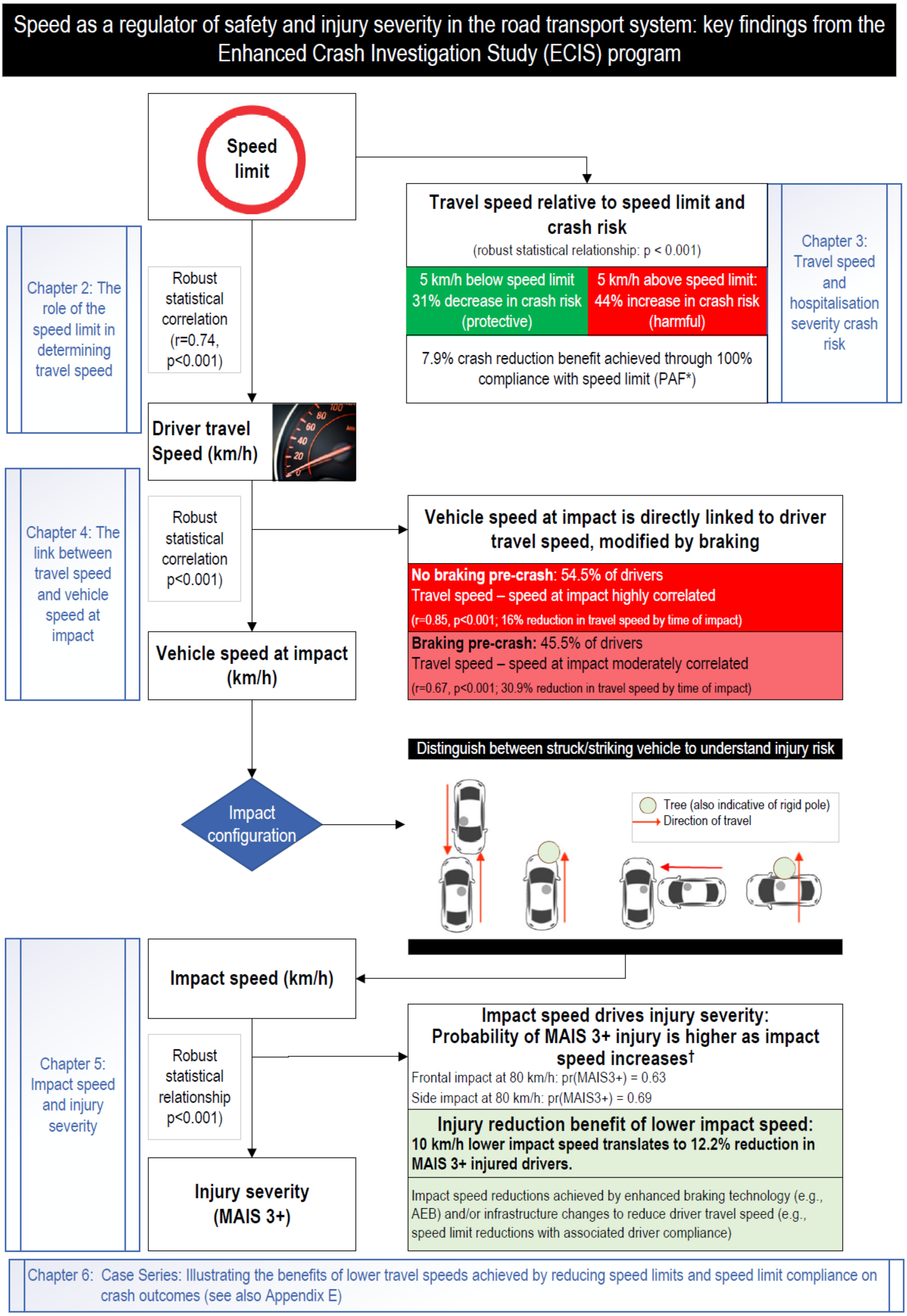
This report set out to examine the role that speed plays in driving crash risk and in shaping injury severity. The findings provide an integrated and comprehensive examination of the role that speed plays in the occurrence and severity of crashes. The findings demonstrate a direct correlation between the speed limit and driver travel speed, while a robust association between travel speed and hospitalisation-severity crash risk was found. With travel speed shown to be linked to the vehicle speed at impact, and impact speed linked to injury severity, the regulating role that the speed limit plays in the level of safety of the road transport system is clear and indisputable. These links are central to the *Vision Zero Model of a Safe Road Transport System* and underpin the *Safe System* approach.

With the goal being the elimination of death and serious injury, the findings provide the basis for a shift in the way speed limits are set. This is reinforced by the finding that crash impact speeds are well beyond the safety limit of vehicles to provide protection for drivers and other occupants, even for many drivers compliant with the speed limit.

The results provide an important foundation on which the implementation of speed-related road safety measures across the *Safe Driver(s), Safe Vehicle(s) and Safe Road(s)* Safe System pillars can be based. These measures include: the appropriate matching of speed limits to the surrounding road environment (Safe Roads) given the safety performance limits of vehicles (Safe Vehicles) and the composition of the passenger vehicle fleet in Victoria; ensuring driver compliance with the speed limits and other requirements (Safe Drivers), and ensuring that enhancements in active and passive vehicle safety not only continue but that the implementation of these measures and the penetration of *Safe Vehicles* into the vehicle fleet are sped up. By adopting this *Safe System* approach and working concurrently across all three elements of the road transport system, the negative role that speed plays as the primary aetiological agent of injury can be addressed.

To conclude, the findings of this research are emphatic: speed plays a fundamental role in determining the safety of the road transport system. This report demonstrates a very clear relationship between the speed limit and driver travel speed, travel speed and vehicle speed at impact, impact speed and injury severity, as well as the negative consequences of drivers exceeding the speed limit. In seeking to reduce, and ultimately eliminate serious injury on our roads, taking the opportunity to address the role that speed plays in driving road trauma is imperative.

GRAPHICAL ABSTRACT



Notes: *PAF: population-attributable fraction; r: correlation coefficient; †based on ECIS sample of hospitalised drivers; pr: probability; AEB: auto-emergency braking
Source: Fitzharris et al. ECIS Report 2: Speed, crash risk and injury severity. Report 344. Monash University Accident Research Centre: Clayton. https://www.monash.edu/muarc

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GLOSSARY AND LIST OF ABBREVIATIONS

4WD	Four-wheel drive vehicle.
AAAM	Association for the Advancement of Automotive Medicine.
ABS	Australian Bureau of Statistics.
ADR	Australian Design Rule.
AEB	Auto Emergency Braking.
AIS	Abbreviated Injury Scale. An internationally recognised anatomical-based coding system for individual injuries. AIS severity scores range from 1 (minor) to 6 (untreatable), with the severity level indicating the threat-to-life assuming that the injury in question is the only injury sustained.
ANCAP	Australian New Car Assessment Program.
ASGS	Australian Statistical Geography Standard.
ATC	Australian Transport Council.
CDC	Collision Deformation Code.[3] A coding system for vehicle collision damage developed by the Society for Automotive Engineers (SAE). The first two digits represent impact direction (on a clock face) and the last digit, the extent of damage (1 minor to 9 severe). The other digits indicate the specific location of damage on the vehicle.
Crash severity	Generic term, also used for the impact severity measures delta-V and EBS.
DELTA-V	Vector difference between impact velocity and separation velocity. In lay terms, it represents the change in velocity of the vehicle during a crash event. Delta-V is usually calculated using damage reconstruction software and the mass and stiffness characteristics of the case vehicle and collision partner must be known. Expressed as km/h.
DMS	Driver Monitoring Systems.
EBS	Equivalent Barrier Speed. Also known as Barrier Equivalent Velocity (BEV). This is the approximate Energy Equivalent Speed (EES) of a vehicle with respect to a 90° fixed, rigid, and flat barrier. EES is the speed at which a vehicle would need to contact any fixed object in order to yield the same observed residual crush.[4] Expressed as km/h.
ECIS	Enhanced Crash Investigation Study.
EDR	Event Data Recorder.
ESC	Electronic Stability Control.
FORS	Federal Office of Road Safety (Australia).
Free travel speed	The speed of a vehicle travelling without impediment (km/h).
GVM	Gross Vehicle Mass.
HREC	Human Research Ethics Committee
ICD	International Classification of Diseases.
Impact speed	Vehicle speed at impact. Impact speed is relevant to injury severity and hence is therefore upon impact configuration in multiple-vehicle crashes where a distinction is made between the striking and struck vehicle. This differs from vehicle speed at impact (see below).
ISA	Intelligent Speed Assist.
Km/h	Kilometres per hour.

3 From SAE J224 (1980), Collision Deformation Classification, SAE International.
4 From ISO 12353-1 (2002), Road vehicles — Traffic accident analysis — Part 1: Vocabulary. ISO.

LKA	Lane Keep Assist.
MAIS	Maximum Abbreviated Injury Scale (score). The highest AIS score in any body region. This is used as an indication of overall injury severity.
MUARC	Monash University Accident Research Centre.
MVC	Multiple-vehicle crash.
NCAP	New Car Assessment Program.
PAF	Population Attributable Fraction. The PAF estimates the percentage of crashes attributable to exceeding the speed limit and is the percentage of crashes in the population that could be eliminated by ensuring compliance with the speed limit.[5,6,7]
PDOF	Principal Direction of Force: The PDOF is the angle of the direction of impulse force acting on the vehicle, measured relative to the longitudinal axis.[8] It is represented as an angle (degrees). The PDOF is linked to delta-V.
RMH	Royal Melbourne Hospital.
SAE	Society of Automotive Engineers (now SAE International).
SD	Standard Deviation.
SRA	Swedish Road Administration, succeeded by the Swedish Transport Administration (Trafikverket).
SUV	Sports Utility Vehicle.
SVC	Single-vehicle Crash.
TAC	Transport Accident Commission.
Travel speed at impact	The speed of the vehicle at the time of impact.
UCSR	Used Car Safety Rating.
UN ECE	United Nations Economic Commission for Europe.
UN GTR	United Nations Global Technical Regulation.
WHO	World Health Organisation.

5 Zapata-Diomedi B, Barendregt JJ, Veerman JL. Population attributable fraction: names, types, and issues with incorrect interpretation of relative risks. British Journal of Sports Medicine 2018;52:212-213.
6 Mansournia MA, Altman DG. Population attributable fraction BMJ 2018; 360.
7 World Health Organisation. Population attributable fraction. https://www.who.int/data/gho/indicator-metadata-registry/imr-details/1287
8 Johnson NS, Gabler HC. Evaluation of NASS-CDS side crash delta-V estimates using event data recorders. Traffic Injury Prevention. 2014;15(8):827-834.

1 INTRODUCTION

1.1 BACKGROUND AND CONTEXT OF THE ENHANCED CRASH INVESTIGATION STUDY (ECIS)

The Transport Accident Commission (TAC), through its role as Victoria's statutory no-fault insurer, has the dual objectives of reducing the number of road-related crashes and facilitating the care, rehabilitation, and other forms of assistance for people injured in crashes.

Since its establishment in 1987 the TAC has implemented a large number of initiatives with the goals of improving road safety and to ensure state-of-the-art trauma care is available in Victoria. These initiatives, along with those implemented by the Victorian Road Safety Partners,[9] have resulted in a 62% reduction in the number of people killed from 1987 to 2019. Despite this apparent success 266 people lost their life on Victorian roads in 2019 and 211 in 2020.[10,11] Across the same time period, however, the number of people injured on Victorian roads has increased.

The *Enhanced Crash Investigation Study (ECIS)* was funded by the TAC in 2013 at a time when the TAC supported 45,038 people injured in road crashes at an annual cost of $1.086 billion.[12] By the end of 2019/20 reporting year, this stood at 59,298 injured road users at a direct annual cost to the TAC of $1.51 billion.[13] Through its work in providing support for people injured in road crashes, the TAC is acutely aware of the significant negative physical and mental health impact of road crashes for those injured, their families and the broader community.[14]

In its most recent strategy, *TAC 2020,*[15] the TAC committed to a vision of zero deaths and serious injuries. The TAC also committed to be the world's leading social insurer. To achieve this, the TAC continues to improve the way it works to ensure the best recovery possible and by providing pathways to independence for those requiring life-long care following a crash.

In parallel, the TAC continues to search for new ways to reach its vision of zero deaths and serious injuries. The TAC works with the Victorian Road Safety Partners to improve road safety most recently through the implementation of the *Victorian Road Safety Strategy 2021-2030,*[16] a strategy that was based on a comprehensive assessment of the number and type of serious injury crashes in Victoria. This was complemented by research evidence as to the effectiveness of road safety countermeasures.

With a high degree of importance placed on evidence-based strategy development, the TAC has a long history of actively supporting research programs that offer insights into how crashes occur, the factors associated with serious injury, and the actions needed to reduce the number of people seriously injured. The ECIS program is one such example of the TAC investing in road safety research, stating that they will 'use the findings of the Enhanced Crash Investigation Study to continually learn and better target future prevention investment'.[10 (p.16)]

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9 Comprised of the Department of Health and Human Services, the Department of Justice and Community Safety, the Department of Transport, the Transport Accident Commission, Victoria Police.

10 Transport Accident Commission. Towards Zero Quarterly Statistics report - December 2019. Geelong: TAC. https://www.tac.vic.gov.au/__data/assets/pdf_file/0012/423210/December-2019-Report-Final.pdf

11 Transport Accident Commission. Lives Lost – Annual: Calendar year to midnight 31 December 2020. Geelong: TAC. http://www.tac.vic.gov.au/road-safety/statistics/lives-lost-annual

12 Transport Accident Commission. 2013 Annual Report. Geelong: TAC; 2013.

13 Transport Accident Commission. 2019/20 Annual Report. Geelong: TAC; 2019.

14 For example, see: Fitzharris M, Fildes B, Charlton J, Kossmann T. General Health Status and Functional Disability Following Injury in Traffic Crashes. Traffic Injury Prevention. 2007;8(3):309-20; Gabbe BJ, Sutherland AM, Hart MJ, Cameron PA. Population-Based Capture of Long-Term Functional and Quality of Life Outcomes After Major Trauma: The Experiences of the Victorian State Trauma Registry. Journal of Trauma. 2010;69(3):532-36; Mayou R, Bryant B. Outcome 3 years after a road traffic accident. Psychological Medicine. 2002;32(4):671-5.

15 Transport Accident Commission. TAC 2020 Strategy. Geelong: TAC; undated.

16 Victorian Government. Victorian Road Safety Strategy 2021 – 2030. Melbourne: Department of Transport; Published 20 December 2020. Available at: https://transport.vic.gov.au/-/media/tfv-documents/road-safety-strategy_dec2020.pdf?la=en&hash=8DB08779EC18DEACB8C91CA2F45B359C

1.2 ECIS OBJECTIVES, PROGRAM STRUCTURE AND BACKGROUND TO THIS REPORT

Given the above context the ECIS program was designed to:

1) Provide the TAC with insight into how serious injury crashes occur.
2) Identify crash prevention measures as well as measures that would be effective in preventing occupants of vehicles being seriously injured once a crash occurs.

To achieve these objectives, the ECIS program consisted of two inter-related components:

1. The in-depth investigation of serious injury crashes through the enrolment and interview of 400 injured and hospitalised drivers, known as the ECIS Case Study.
2. Measurement of travel speed and subsequent survey of drivers at selected crash locations, known as the ECIS Control Study.

With the ECIS Case Study being the basis for understanding the factors associated with crash involvement and injury severity, the findings of the ECIS program relate to crashes where an involved driver required admission to hospital for the treatment of one or more injuries sustained. All findings of the ECIS program must be interpreted within this context.

The findings of the ECIS program are presented over four reports, with this being the second report in the series. The first report, *ECIS Report 1*, utilised the data from the ECIS Case Study and the ECIS Control Study to conduct a comprehensive examination of the factors associated with the occurrence of serious injury passenger vehicle crashes. In doing so, a distinction was also made with regard to the severity of injuries sustained using the Maximum Abbreviated Injury Scale (MAIS) score. With a further focus of the ECIS program being on measures to mitigate and ultimately eliminate serious injury, a detailed analysis of factors associated with serious injury, defined as MAIS 3+ severity, was conducted.

The *ECIS Report 1* also presented an assessment of the performance of the Victorian road transport system against its inherently safe form where serious injury is eliminated. This concept stems from the *Vision Zero Model of Safe Travel* and the *Safe System* approach that posits once pre-defined Safe Driver, Safe Vehicle, and Safe Roads criteria are met drivers and passengers are protected from serious injury. Recognising the inherent physical limitations and vulnerability of the human body to withstand injury when exposed to force at impact,[17] the Safe Driver, Safe Vehicle, and Safe Roads criteria act in combination to limit the amount of force that the human body experiences in a crash. This energy control principle is based on the field of impact biomechanics where the level of energy (i.e., half the mass x velocity squared) that the human body can tolerate without injury is well understood.[18,19,20,21]

By definition, the level of energy in the road transport system is a product of vehicle speed. This was explicitly recognised in the *Vision Zero Model of Safe Travel* where the speed limit was represented as an explicit design parameter (Figure 1.1). [22,23,24] Speed is seen to be a critical regulator of the level of safety in the system. Here it is important to state that the speed limit needs to be set on the basis of the available road safety infrastructure, foreseeable crash types and impact configurations, and the safety of the vehicle fleet. Failure to do so means that when a crash occurs the energy of the crash exceeds the design specification of the vehicle, the consequence of which is that the driver and other occupants will be injured. The severity of the injury is driven almost exclusively by the degree to which the crash energy exceeds the crashworthiness, or safety, of the vehicle. This is a critical point as it explicitly recognises the limits of engineering to protect drivers from high levels of force

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17 Vision Zero and by extension the Safe System approach drew on the work of Haddon, whose description of 'crash packaging' forms the basis of modern occupant protection strategies. In this kinetic energy model, the prevention of injury is a consequence of countermeasures that act to ensure that the mechanical forces a driver (and occupants) is exposed to remain below the threshold level where injury is known to occur; this limit is often expressed as the tolerance of the human body to injury (or similar).

18 Nahum AM, Melvin JW. (Eds.). Accidental Injury: Biomechanics and Prevention. New York: Springer-Verlag; 2002.

19 Belin M-Å, Tillgren P, Vedung E. Vision Zero – a road safety policy innovation. International Journal of Injury Control and Safety Promotion. 2012;19(2):171-9.

20 Kristianssen A-C, Andersson R, Belin M-Å, Nilsen P. Swedish Vision Zero policies for safety – A comparative policy content analysis. Safety Science. 2018;103:260-9.

21 From rapid deceleration and/or direct impact.

22 Tingvall C, Lie A, Johansson R. Traffic Safety in Planning - A Multidimensional Model for the Zero Vision. In: von Holst H, Nygren Å, Andersson ÅE, editors. Transportation, Traffic Safety and Health — Man and Machine: Second International Conference. Brussels, Belgium: Springer Berlin Heidelberg; 1996, Published 2000. p. 61-9.

23 This is described in full in ECIS Report 1, chapter 1.

24 Larsson P, Dekker SWA, Tingvall C. The need for a systems theory approach to road safety. Safety Science. 2010;48(9):1167-74.

associated with high impact speeds. It is for this reason that the speed limit is viewed as the critical regulator of the safety of drivers (and occupants).

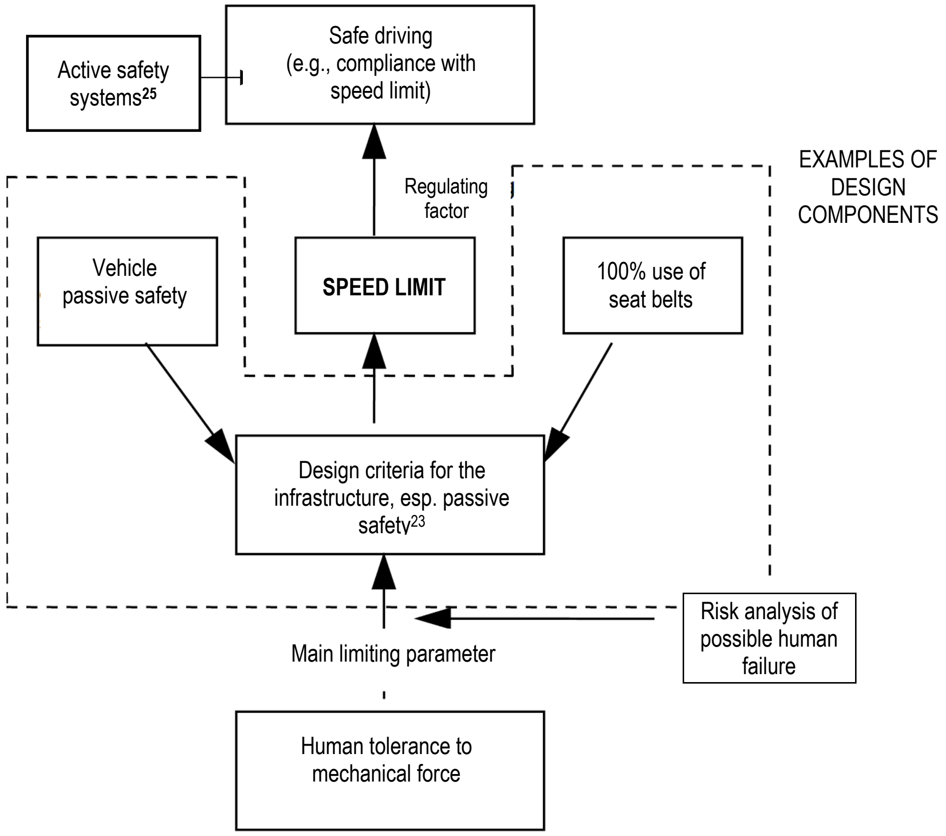

FIGURE 1.1 ADAPTED VERSION OF THE MULTI-DIMENSIONAL (VISION ZERO) MODEL FOR SAFE TRAVEL IN A VEHICLE[25,26,27]

That the speed limit acts as a regulator of system safety is premised on the following relationships:

1. Travel speed is correlated with speed limits.[28]
2. Impact speed is associated with travel (i.e., operating) speed.[29]
3. Injury severity is associated with impact speed (i.e., velocity).[30]

These relationships, and those shown in the *Vision Zero model,* explain why the level of serious injury is so high on high-speed roads as shown in *ECIS Report 1*. Furthermore, these relationships explain why even drivers compliant with the speed limit were seriously injured, defined as MAIS 3+ severity. Exceeding the speed limit simply exacerbates this risk by breaching the system boundaries. It is for this reason that ensuring compliance with speed limits is imperative, noting however this alone is insufficient to guarantee protection against serious injury in the event of a crash for reasons explained above.

25 Tingvall C, Lie A, Johansson R. Traffic Safety in Planning - A Multidimensional Model for the Zero Vision. In: von Holst H, Nygren Å, Andersson ÅE, editors. Transportation, Traffic Safety and Health — Man and Machine: Second International Conference. Brussels, Belgium: Springer Berlin Heidelberg; 1996, Published 2000. p. 61-9.
26 Note: passive safety in this context relates to the energy absorption capability of road infrastructure. Active vehicle safety systems can be accounted for here given their influence on pre-crash vehicle dynamics and/or velocity, which in turn can influence impact speed. These considerations flow into the setting of speed limits, given driver compliance as shown by 100% use of seat belts in this example and the level of occupant protection of the vehicle itself (i.e., passive safety).
27 Eugensson A, Ivarsson I, Lie A, Tingvall C. Cars are driven on roads, joint visions and modern technologies stress the need for co-operation, Paper Number 11-0352. The 22nd International Technical Conference on the Enhanced Safety of Vehicles (ESV) Washington, D.C., June 13-16, 2011.
28 Yang J, Xu J, Gao C, Bai G, Xie L, Li M. Modelling of the Relationship Between Speed Limit and Characteristic Speed of Expressway Traffic Flow. Sustainability 2019;11,(4621).
29 TRB. Special Report 254: Managing Speed: Review of Current Practice for Setting and Enforcing Speed Limits. Washington, DC: Transportation Research Board; 1998.
30 Doecke SD, Baldock MRJ, Kloeden CN, Dutschke JK. Impact speed and the risk of serious injury in vehicle crashes. Accident Analysis & Prevention. 2020;144:105629.

While the rationale for ensuring driver compliance is clear, ensuring that the speed limit is set in accordance with the surrounding road infrastructure and environment, as well as the limitations of the human and the vehicle, is fundamental to the overall safety of the road transport system. By failing to set the speed limit correctly, the driver is placed at risk of serious injury, even when the vehicle meets the required safety criteria, **and** the driver obeys the speed limit. This is because the crash occurs at an impact speed outside of the safety envelope of the vehicle.

While passive vehicle safety systems play a key role in protecting occupants from serious injury, the development and implementation of active safety systems represents an important step in the evolution of vehicle safety and safe driving. Systems that advise the driver or intervene when the driver deviates from the lane (i.e., Lane Keep Assist, LKA), exceeds the speed limit (i.e., Intelligent Speed Assist, ISA) and/or automatically applies the brakes when an impending collision is detected (i.e., Autonomous Emergency Braking, AEB) will all play an important role in ensuring safe driving, as will driver monitoring systems (DMS) that continually assess driver drowsiness and inattention. These systems will not only act to prevent crashes but will mitigate the severity of injury by reducing the impact speed of the crash. As a consequence, the injury reduction benefits of the *Safe Vehicle* and the *Safe Road* infrastructure can be fully realised.

Independent of the *Vision Zero* model, previous research has demonstrated a strong relationship between travel speed and crash risk.[31,32,33,34,35,36,37] This research has shown that the travel speed of individual drivers and the mean travel speed are associated with an elevated crash risk. The research methods used to derive these findings included in-depth crash investigation studies and pre-post studies of speed limit changes. Given the strength of these findings, the control of travel speed through the setting of safe speed limits and the enforcement of these limits to ensure high levels of driver compliance are key road safety countermeasures.[38]

In examining the role of travel speed in the road transport system, an important distinction needs to be made between travel speed associated with crash occurrence and impact speed being associated with injury severity. This report aims to explore both of these relationships. In addition, this report will provide examples of how changes in pre-crash driver behaviour can reduce the number of hospitalisation crashes and serious injury.

1.3 REPORT OBJECTIVES

The objective of this report is to build on the findings presented in the *ECIS Report 1* with respect to the role that speed plays in crash occurrence and on the severity of injuries sustained.

This report aims to provide a comprehensive analysis of the role of vehicle speed and its impact on road safety by addressing the following five questions:

1. What is the relationship between the speed limit and travel speed?
2. What is the relationship between travel speed and the risk of involvement in a crash that results in one or more involved drivers being hospitalised (referred to as *hospitalisation-severity crash risk)*?
3. What is the relationship between the travel speed of a vehicle and the speed of the (same) vehicle at impact, the frequency of pre-crash avoidance actions and the effect, if any, of these actions on the speed of the vehicle at impact?
4. What is the relationship between impact speed and injury severity?
5. What is the injury reduction benefit of lower impact speeds?

In addition to these five questions, this report seeks to illustrate the potential benefits of reduced travel speed, speed limit compliance and reduced impact speed on crash and injury severity outcomes using a case series approach.

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31 Aarts L, van Schagen I. Driving speed and the risk of road crashes: A review. Accident Analysis & Prevention. 2006;38(2):215-24.
32 Elvik R. Speed Limits, Enforcement, and Health Consequences. Annual Review of Public Health. 2012;33(1):225-38.
33 Elvik R, Vadeby A, Hels T, van Schagen I. Updated estimates of the relationship between speed and road safety at the aggregate and individual levels. Accident Analysis & Prevention. 2019;123:114-22.
34 Kloeden CN, Ponte G, McLean AJ. Travelling speed and the risk of crash involvement on rural roads, CR204. Canberra: Australian Transport Safety Bureau; 2001.
35 Kloeden CN, McLean AJ, Moore VM, Ponte G. Travelling speed and the risk of crash involvement. Volume 1 - Findings, CR 172. Canberra: Federal Office of Road Safety; 1997.
36 Nilsson G. Traffic safety dimensions and the power model to describe the effect of speed on safety. Bulletin 221, Lund Institute of Technology, Lund; 2004.
37 Shinar D. Speed and safety. In: Traffic Safety and Human Behavior: Second Edition. UK: Emerald Publishing Limited; 2017.
38 Elvik R, Vaa T, Hoye A, Sorenson M. The Handbook of Road Safety Measures: Second Edition. UK: Emerald Publishing Limited; 2009.

It is anticipated that the findings of this report will engender a better understanding of the role that speed plays and its various inter-dependencies that underpin the *Vision Zero Model of Safe Travel* and the *Safe System* approach. As such, it is hoped that the insights gained from these analyses will serve to motivate actions that will act to reduce and ultimately eliminate serious injury on Victorian roads.

1.4 STRUCTURE OF THIS REPORT

The results of this report are presented across a series of chapters, each addressing one of the five questions described above. Key features of the ECIS program structure and method are described within each chapter. A full description of the analysis method is presented within each chapter. To orient the reader and to assist in understanding the data used in this report in the context of the ECIS program and *ECIS Report 1*, a description of the data used in each chapter including its source and rationale for use is provided in Appendix F.

The reader is referred to *ECIS Report 1* for comprehensive coverage of the ECIS study method.

1.5 ETHICS AND DATA ACCESS APPROVALS

The conduct of the ECIS Case Study was approved by The Alfred Hospital Research Ethics Committee (HREC, Project: 249-14), The Royal Melbourne Hospital HREC (Project: 249-14), and the Monash University HREC (CF14/2329-2014001254).

The conduct of the ECIS Control study was approved by the Monash University Human Research Ethics Committee (HREC) (CF14/1930-2014000983).

1.6 ECIS REPORT SERIES

The findings of the ECIS program are presented across four Reports. These *Reports* are available at the MUARC website.

ECIS REPORT 1 **OVERVIEW AND ANALYSIS OF CRASH TYPES, INJURY OUTCOMES AND CONTRIBUTING FACTORS**

This report provides the rationale for the ECIS program, and a description of the study methods and key findings. Findings include details of the crashes and injury outcomes overall and by crash type, an analysis of contributing factors for both crash occurrence and injury severity, and a detailed examination of the safety of Victoria's road transport system as it applies to drivers and occupants of passenger vehicles. This Report aims to provide a comprehensive understanding of serious injury crashes. The findings form the basis of identifying future road safety countermeasures aimed at eliminating serious injuries.

ECIS REPORT 2 **SPEED, CRASH RISK AND INJURY SEVERITY**

This report examines the role of speed in shaping crash risk and injury severity. The report examines five key questions: 1. The relationship between the speed limit and travel speed; 2. The relationship between travel speed and the risk of involvement in a crash that results in one or more involved drivers being hospitalised; 3. The relationship between travel speed and vehicle speed at impact, the frequency of pre-crash avoidance actions and the effect, if any, of these actions on the speed of the vehicle at impact; 4. The relationship between impact speed and injury severity, and 5) The injury reduction benefit of lower impact speeds. A case series approach was used to illustrate the potential benefits of reduced travel speed, speed limit compliance and impact speed on crash and injury severity outcomes.

Key inputs to this analysis are the estimates of travel speed and impact speed obtained through the crash reconstruction process and the 'free travel speed' data obtained from ECIS Control Study drivers.

The Report presents practical examples of the effect of reducing travel speed on crash outcomes using crash reconstruction methods.

ECIS REPORT 3 **UNDERSTANDING CONTRIBUTING FACTORS FOR SERIOUS INJURY CRASHES USING CRASH CHAIN ANALYSIS**

This report aims to highlight key safety gaps and trauma risk in the road transport system in Victoria that lead to serious injury. The focus of the report is two-fold: 1. identifying factors associated with serious injury crashes occurring, and 2. identifying factors associated with serious injury, given that a crash occurs. Analysis is presented by crash type using a road trauma '*integrated safety chain*' model developed during the ECIS program. The Report sets the basis for ECIS Report 4.

ECIS REPORT 4 **IDENTIFICATION OF COUNTERMEASURES TO ADDRESS SERIOUS INJURY CRASHES**

This report identifies interventions and actions aimed at reducing the incidence of serious injury sustained in crashes in Victoria. Interventions are focussed on short-to-medium term actions, as well as setting a path towards the longer-term vision of creating an inherently safe road transport system. Countermeasures are presented across the phases of the crash, from before a driver enters a vehicle through to recovery from injuries sustained in the crash. This analysis highlights where, and by what means, reductions in serious injury can be achieved.

2 THE ROLE OF THE SPEED LIMIT IN DETERMINING TRAVEL SPEED

This chapter examines the first of the five questions that are the subject of this report, namely: What is the relationship between the speed limit and travel speed? This represents the first link in understanding the role that the speed limit plays in shaping the level of safety in the road transport system.

2.1 TRAVEL SPEED DATA

To examine travel speed choice, the travel speed of ECIS Case drivers involved in Lane Departure crashes and their matched ECIS Control drivers was used. Limiting the analysis in this way means that the relationship between the speed limit and driver speed choice is examined without the influence of any turning manoeuvres on travel speed. The data used in this analysis is described below.

ECIS Case data

The travel speed data of 238 drivers involved in 172 Lane Departure crashes was used (SVC: n = 106; MVC 2-vehicle crashes, MVC: n = 66). Of the 172 Lane Departure crashes, 102 were used as ECIS Control sites (SVC: n = 60; MVC: n = 42) and 70 were not (SVC: n = 46; MVC: n = 24). To maximise the dataset, travel speed data estimated using the Type-A and Type-B crash reconstruction method was used (see Appendix A).

ECIS Control data

The 'free' travel speed of vehicles passing through the location where an ECIS Lane Departure crash occurred was recorded using a laser speed camera. Vehicles were observed within a 30-minute window of the known crash time on the same weekday. The 'free' speed of **all** vehicles was recorded. The ECIS Control study data collection method is described in full in *ECIS Report 1* and Appendix B.

Travel speed observations were recorded at 102 of the 172 Lane Departure crash sites. In total, the travel speed of 1,942 vehicles was recorded at the 102 crash sites. A total of 727 drivers were associated with 60 single-vehicle Lane Departure crashes and 1,215 drivers were associated with 42 multiple-vehicle Lane Departure crashes. All observed 'free' travel speed data were used in the analysis, including drivers who did not return the ECIS Control Questionnaire as no person-related data (i.e., age, sex) was required in this correlational analysis.

Combined dataset

In total, the travel speed of 2,180 drivers was used. This forms the basis of assessing driver speed choice and the correlation between driver speed choice and the speed limit.

2.2 DRIVER SPEED CHOICE BY SPEED ZONE

The speed choice of drivers for each speed limit zone is presented in Table 2.1. This includes the mean speed, the median speed (50% percentile), the 85th percentile speed and the percent of drivers exceeding the speed limit by 3 km/h or more and 5 km/h or more. The number of sites and the number of vehicles included in each speed zone is also presented in Table 2.1.

TABLE 2.1 OBSERVED TRAVEL SPEED BY SPEED ZONE

SPEED LIMIT (KM/H)	NUMBER OF ROAD LOCATIONS / CRASHES	NUMBER OF VEHICLE OBSERVATIONS	TRAVEL SPEED (KM/H)				
			MEAN (SD)	MEDIAN	85TH%	EXCEEDING BY ≥ 3 KM/H	EXCEEDING BY ≥ 5 KM/H
50	8	82	45.3 (8.7)	47.0	52.6	14.6%	8.5%
60	34	396	56.1 (10.7)	56.0	64.0	19.2%	14.6%
70	15	268	69.8 (10.2)	70.0	79.0	38.1%	28.4%
80	25	466	73.6 (10.5)	75.0	81.9	12.4%	8.2%
90	4	77	83.1 (8.7)	85.0	91.3	11.7%	5.2%
100	82	847	88.9 (14.8)	94.0	101.0	8.1%	4.8%
110	4	44	97.8 (15.5)	105.5	110.3	4.5%	2.3%
All	172	2180	N/A	N/A	N/A	15.0%	10.3%

In each speed zone, the mean speed and the median speed were marginally lower than the speed limit. The 85th% speed is presented for reference only.

Across all roads and speed limit zones, the proportion of drivers exceeding the speed limit by 3 km/h or more was 15.0% while this was 10.3% for exceeding the speed limit by 5 km/h or more. Speed limit compliance was highest on roads with a 100 km/h and 110 km/h speed limit. Compliance with the speed limit was lowest in 70 km/h speed limit zones.

These data demonstrate the direct link between the speed limit and driver speed choice.

2.3 CORRELATION BETWEEN SPEED LIMITS AND TRAVEL SPEED

To examine the relationship between the speed limit and travel speed a correlation analysis was performed. The correlation between observed travel speed and the speed limit among the 2,180 drivers was 0.738 ($p < 0.001$). This relationship is reflected in Figure 2.1.

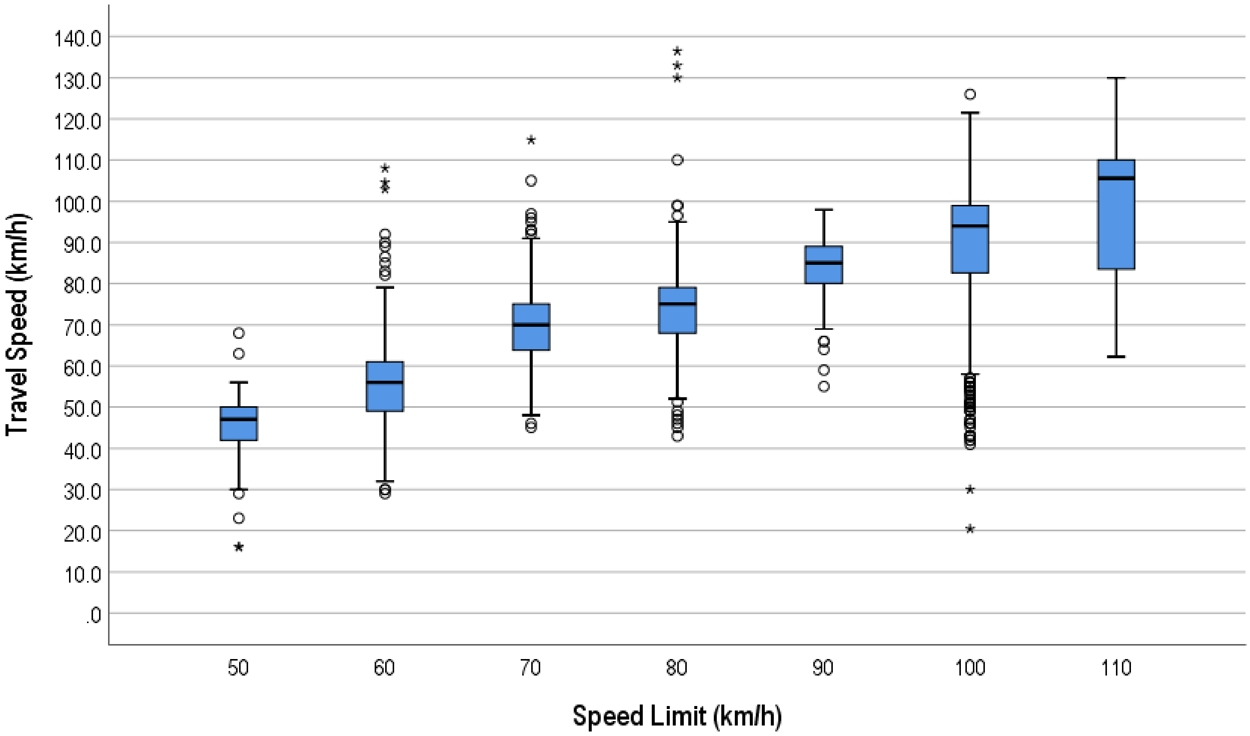

FIGURE 2.1 BOX PLOT OF TRAVEL SPEED BY SPEED LIMIT[39]

These data highlight the strong relationship between driver speed choice and the speed limit. While not unexpected, these findings reinforce the critical role speed limits play in shaping driver speed choice. It is recognised that factors such as the surrounding traffic, the time the speed limit has been in place, and the level of police enforcement will all exert an influence on speed choice. How drivers respond to speed limit changes is beyond the scope of this report; however, it could be postulated that after a period of acclimatisation drivers would likely exhibit speed choice behaviour that would mirror the correlation with the speed limit shown above. From a safety perspective, ensuring a rapid behavioural transition is key.

As described in chapter 1 (p.2), this relationship is the first in a series of relationships that form the basis of speed being viewed as the critical regulator of the safety of the road transport system.[40] The following sections explore the relationship between travel speed and impact speed, followed by the relationship between impact speed and injury severity. First, the relationship between travel speed and crash risk is examined.

39 Box plot shows the following: median (horizontal line) with the box itself bounded by the 25th percentile (Q1) and the 75% percentile (Q3); this is the interquartile range (IQR). The lower capped lines give the 'minimum' (= Q1 - 1.5*IQR) while the upper capped line is the 'maximum' (= Q3 + 1.5*IQR). Outliers are shown by circles (o) and extremes are shown by Asterix (*).

40 Tingvall C, Lie A, Johansson R. Traffic Safety in Planning - A Multidimensional Model for the Zero Vision. In: von Holst H, Nygren Å, Andersson ÅE, editors. Transportation, Traffic Safety and Health — Man and Machine: Second International Conference. Brussels, Belgium: Springer Berlin Heidelberg; 1996, Published 2000. p. 61-9.

3 TRAVEL SPEED AND HOSPITALISATION-SEVERITY CRASH RISK

This chapter examines the relationship between travel speed and hospitalisation-severity crash risk. This is done by comparing the travel speed of vehicles involved in a crash to the travel speed of vehicles measured at the same location that did not crash. This takes advantage of the matched Case-Control design implemented in the ECIS program. The derived crash risk estimate was calculated as being relative to travelling at the speed limit. This provides an understanding of the change in crash risk associated with travelling below and in excess of the speed limit.

3.1 OBJECTIVE

As presented in *ECIS Report 1*, a robust relationship between travel speed and crash risk was found. This chapter expands on this analysis by presenting detail on the characteristics of these crashes, the drivers involved and the travel speed profile.

The inclusion of driver age and driver sex in the statistical models also meant that the relationship between driver age and driver sex on crash risk could be reported. This is also valuable from the perspective of accounting for any underlying differences in speed choice that may be characteristic of drivers of a particular age or sex.

Of further interest was the crash reduction benefit associated with 100% driver compliance with the speed limit.

As the 'outcome' is crash-involvement, the findings are relevant only to crashes where an involved driver required hospitalisation for the treatment of injuries sustained in the crash as this was the sample from which 'Cases' were drawn. Interpretation of the term 'crash risk' in this report must be understood within this definition; the term, 'hospitalisation-severity crash risk' is used in this report.

3.2 METHOD

A full description of the Case-Control study design and its application in the ECIS program is presented in *ECIS Report 1*. Details of the Case selection process and the analysis approach are provided here.

3.2.1 Terminology, design, and travel speed

The estimation of the relationship between travel speed and crash risk is achieved by comparing the travel speeds of crash-involved vehicles with vehicles not involved in a crash. Drivers of these vehicles are referred to as 'Case' and 'Control' drivers respectively. For reference, key terminology is as follows:

- **ECIS Case -** A selected ECIS crash (or driver). The travel speed of the involved drivers(s) was determined through the Type A crash reconstruction process (see Appendix A).
- **ECIS Control -** The Control site is the location where an ECIS crash occurred and where the free speed of Control drivers was measured, while the Control driver is a driver travelling through the known crash site but did not crash. Vehicle speed was recorded using a LaserCam4 (Kustom Signals, Lenexa, KS, USA) laser speed camera.

Vehicles are referred to as either an 'A-vehicle' or a 'B-vehicle'. The naming conventions for the involved ECIS Case and ECIS Control vehicles are presented in Table 3.1.

TABLE 3.1 NAMING CONVENTIONS FOR VEHICLES INVOLVED IN ECIS CRASHES AND ASSOCIATED ECIS CONTROL VEHICLES

ECIS CASE-CONTROL NAMING CONVENTION	DETAIL
A-vehicle	**Relevant for single-vehicle crashes (SVC) and multiple-vehicle crashes (MVC)**
ECIS Case (A-vehicle)	The injured driver enrolled to the ECIS Case Study upon admission to hospital.
A-vehicle Control	Drivers travelling in the same direction at the same location as the ECIS Case A-vehicle driver.
B-vehicle	**Relevant for multiple-vehicle crashes only (MVC)**
ECIS B-vehicle	For multiple-vehicle crashes, refers to the other crash-involved driver.
B-vehicle Control	For multiple-vehicle crashes, drivers travelling in the same direction at the same location as the ECIS B-vehicle.

To ensure optimal matching of the travel speed of the ECIS Case vehicles and the Control vehicles, Control vehicles were observed on the same day of the week as the ECIS Crash and within a 30-minute time-window of the known crash time. This was done in order to match the traffic conditions to the time of the crash. The direction of travel and manoeuvre were matched to the relevant crash-involved vehicle. This ensures that the speed profile of the vehicles being compared was not confounded by vehicle manoeuvres or travel direction factors (e.g., sight distance, heading angle, slope). The statistical analysis explicitly takes advantage of this study design (see 3.2.4, Data Analysis).

Whilst all drivers admitted to the study hospitals were eligible for the ECIS Case study and with no restriction on the time of day of the crash, 'Control driver' travel speed data were not collected where the crash occurred on toll roads for reasons of safe access. Similarly, 'Control driver' travel speed data were not collected on very low traffic volume rural roads where the crash occurred at night due to the inability to collect sufficient vehicle data close to the crash time, as well as for logistical reasons (see *ECIS Report 1*, chapter 2 & Appendix C). Drivers were included as an ECIS Control driver upon the return of a questionnaire to the ECIS Team which was matched to their travel speed. The response rate was 33.2% (Appendix B.4).

3.2.2 Defining crash types based on vehicle movement

Crashes were classified according to vehicle movement with secondary consideration given to the roadway location (Figure 3.1). Crashes were defined as:

1. Lane Departure crashes. Includes crashes where a single-vehicle left the carriageway to the left or to the right, and multiple-vehicle head-on crashes, either on a curve or on a straight road section.
2. Across Path crashes. Includes crashes where a vehicle: moved across the path of another vehicle when entering a carriageway; turned across the path of another vehicle; or moved across the path of traffic without turning (i.e., going straight), such as at a standard 4-way intersection.

The ECIS driver can be the occupant of either crash-involved vehicle in each of the crash type scenarios.

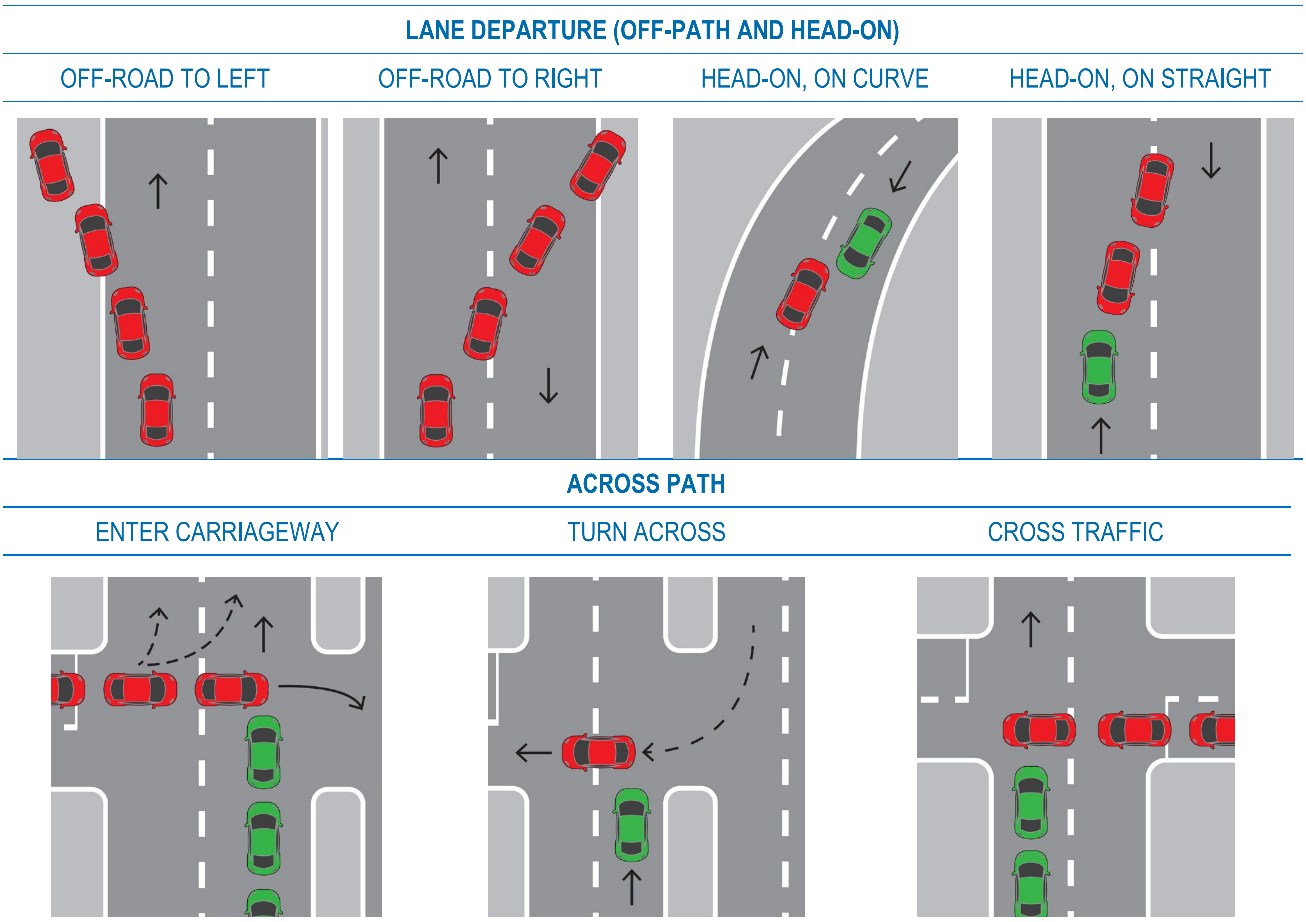

FIGURE 3.1 REPRESENTATION OF CRASH TYPES

Key: Vehicle (red): signifies the critical pre-crash vehicle movement; Vehicle (green): signifies the vehicle travelling in its normal path and involved in the crash. The ECIS A-vehicle (Case) driver can be the occupant of either of the crash-involved vehicles in each of the crash type scenarios.

3.2.3 ECIS Case-Control dataset

This section describes the number and type of crashes included in the Case-Control analysis as well as the number of Control drivers associated with these crashes. Attention is paid to alcohol and/or illicit drug (AOD) use by drivers and the implications for assessing the relationship between travel speed and hospitalisation-severity crash risk.

3.2.3.1 Number of ECIS crashes and associated Control drivers

The ECIS program used two crash reconstruction methods, defined as Type-A and Type-B (Appendix A). The Type-A method used a 3D representation of the scene while the Type-B method used a 2D representation of the scene. The analysis was limited to crashes where the Type-A reconstruction method was used. This was based on the very high level of confidence in the travel speed estimate obtained from the Type-A crash reconstruction method due to using all relevant friction coefficient values for all surfaces and the 3D representation of the crash scene; standardised friction coefficient values were used.

A total of 170 crashes were reconstructed using the Type-A method. For consistency, one crash was excluded from the analysis as it involved a cyclist and two crashes were excluded due to complex vehicle movements and multiple vehicles (> 2) being involved.

The ECIS Case-Control analysis set therefore initially comprised 167 crashes. Of these, 97 were Lane Departure crashes (58.1%; SVC: n = 55, 56.7%; MVC: n = 42, 43.3%) and 70 were Across Path crashes (41.9%). There were 279 drivers involved in these 167 crashes (A-vehicle: 167 drivers; B-vehicle: 112 drivers).

The number of Control drivers matched to the A-vehicle drivers and B-vehicle drivers is presented in Table 3.2. These were drivers observed travelling through the same location as the ECIS crash of interest. The free (i.e., unimpeded) travel speed of vehicles within a 30-minute time window of the crash was captured using a laser speed measuring device. To ensure the measured Control Vehicles were representative of the population of vehicle driving through the crash site all vehicles were measured. Nine drivers matched to both the A-vehicle and to the B-vehicle (where relevant) closest to the crash time were sent a detailed survey. The response rate was 33.2%. Further detail on the ECIS Control study is provided in *ECIS Report 1* and Appendix B.

Due to the need to include driver age and driver sex in the statistical models only, drivers who provided informed consent to participate in the study were included. The matched Control sample therefore consisted of 1,230 drivers (A-vehicle Control drivers: 756; B-vehicle Control drivers: 474).

The ratio of Control drivers to Case drivers was 4.4 overall, with this being 4.5:1 for A-vehicle drivers and 4.2:1 for B-vehicle drivers. This compares favourably with the goal at the commencement of the ECIS program of obtaining a control-to-case ratio of 3.0:1.[41,42] Given the time and cost associated with Case data collection and the statistically rare nature of serious injury crashes in the population, the use of multiple Control drivers per case maximises statistical power.[41,43] This approach ensures an efficient study design as fewer Cases are required to detect the presence of an effect of travel speed on crash involvement.

TABLE 3.2 NUMBER OF ECIS CASE VEHICLE DRIVERS AND ASSOCIATED ECIS CONTROL DRIVERS

ECIS CASE-CONTROL DRIVER TYPE	ALL CRASH TYPES	CRASH TYPE	
		LANE DEPARTURE	ACROSS PATH
ECIS A-vehicle drivers (Case)	**167**	**97**	**70**
A-vehicle Control	756	481	275
A-vehicle Control : Case ratio	4.5:1	5.0:1	3.9:1
ECIS B-vehicle drivers	**112**	**42**	**70**
B-vehicle Control	474	220	254
B-vehicle Control : Case ratio	4.2:1	5.2:1	3.6:1
ECIS Case drivers (A | B)	**279**	**139**	**140**
A | B Control	1,230	701	529
A | B Control : Case ratio	4.4:1	5.0:1	3.8:1

41 Rothman KJ. Epidemiology. New York: Oxford University Press; 2002.
42 Altman DG. Practical Statistics for Medical Research. Boca Raton: Chapman and Hall/CRC; 1990.
43 Breslow N. Design and Analysis of Case-Control Studies. Annual Review of Public Health, 1982; 3:29-54.

For completeness, in six crashes both drivers involved in the crash were enrolled as ECIS Case drivers. For these six crashes, the driver first enrolled to the ECIS Case Study was nominated as the A-vehicle driver with the subsequent driver enrolled being classified as the B-vehicle driver.

3.2.3.2 Presence of alcohol and other drugs (AOD) among Case and Control drivers

The presence of AOD among ECIS Case drivers

Driving under the influence of alcohol and/or illicit drugs (AOD) has been shown to increase crash risk.[44] Given this, the inclusion of crash-involved drivers with an illegal BAC and/or having used illicit drugs prior to driving in the analysis of the relationship between travel speed and crash risk may lead to a biased estimate. This is because a portion of the travel speed - hospitalisation-severity crash risk estimate may reflect the influence of AOD; this is referred to as *confounding*.

Among the 167 crashes described above there were 21 crashes where AOD use was indicated (12.6%) (Table 3.3). This was higher for Lane Departure crashes (17.5% of n = 97) than for Across Path crashes (5.7% of n = 70) ($p \leq 0.05$). In each of the 21 crashes, one driver was positive for AOD use. With 279 drivers involved in these 167 crashes, the proportion of drivers AOD positive was 7.5% (n = 21 of 279). The proportion of A-vehicle drivers AOD positive was slightly higher (8.9%, 15 of 167; BAC: n = 5; Illicit: n = 8; BAC + Illicit: n = 2) than was the case for B-vehicle drivers (5.3%, 6 of 112; BAC: n = 1; Illicit: n = 2; BAC + Illicit: n = 3).

TABLE 3.3 CRASHES WHERE A DRIVER WAS UNDER THE INFLUENCE OF ALCOHOL AND/OR ILLICIT DRUGS

ALCOHOL AND/OR DRUG (AOD)-RELATED CRASH	ALL CRASH TYPES (n = 167)	CRASH TYPE	
		LANE DEPARTURE (n = 97)	ACROSS PATH (N = 70)
AOD-related crash	12.6% (n = 21)	17.5% (n = 17)	5.7% (n = 4)
BAC only	3.6% (n = 6)	4.1% (n = 4)	2.8% (n = 2)
Illicit only	6.0% (n = 10)	8.2% (n = 8)	2.8% (n = 2)
BAC + Illicit	3.0% (n = 5)	5.2% (n = 5)	0.0% (n = 0)
AOD not present	87.4% (n = 146)	82.5% (n = 80)	94.3% (n = 66)

That 12.6% (n = 21) of crashes involved one driver having an illegal BAC and/or an illicit drug present in their body at the time of the crash shows that consideration needs to be given to the potential confounding effect of AOD use when estimating the association between travel speed and crash risk. The characteristics of these 21 crashes are therefore of interest, particularly travel speed.

First, in 18 of the 21 crashes (85.7%) where an AOD positive driver was involved, a driver and/or occupant sustained an MAIS 3+ injury, highlighting the high severity nature of these crashes.

Second, AOD positive drivers were significantly more likely to be exceeding the speed limit than non-AOD drivers (Table 3.4). Of the 21 AOD positive drivers, 61.9% (n = 13) were exceeding the speed limit prior to the crash (2 by 1.0 – 4.9 km/h; 3 by 5.0 – 9.9 km/h; 8 by 10+ km/h). By comparison, 19.4% (n = 50 of 258) of non-AOD drivers were exceeding the speed limit prior to the crash ($p \leq 0.05$; RR: 3.19, 95% CI: 2.10 – 4.85). It also appears that AOD drivers were exceeding the speed limit by a greater amount than non-AOD drivers, however the small number of drivers in the AOD travel speed categories precludes statistical testing.

TABLE 3.4 TRAVEL SPEED FOR AOD AND NON-AOD CASE DRIVERS

TRAVEL SPEED	ALL DRIVERS (N = 279)	AOD DRIVERS (N = 21)	NON-AOD DRIVERS (N = 258)
At or below speed limit	77.4% (n = 216)	38.1% (n = 8)	80.6% (n = 208)
Exceed speed limit	**22.6%† (n = 63)**	**61.9% (n = 13)**	**19.4%† (n = 50)**
By 1.0 – 4.9 km/h	10.0% (n = 28)	9.5% (n = 2)	10.1% (n = 26)
By 5.0 – 9.9 km/h	5.4% (n = 15)	14.3% (n = 3)	4.7% (n = 12)
By 10.0 + km/h	7.2% (n = 20)	38.1% (n = 8)	4.7% (n = 12)

† exceed speed sub-categories have rounding error of +0.1% with use of 1 decimal place.

44 Shinar D. Traffic Safety and Human Behavior: Second Edition. UK: Emerald Publishing Limited; 2017.

These data provide evidence that driving under the influence of AOD is associated with increased likelihood of exceeding the speed limit. This is an important consideration when attempting to isolate the effect of travel speed on crash risk from other factors.

These results highlight the likely confounding influence of AOD use on the relationship between travel speed and crash risk. For this reason, the removal of these crashes from the Case-Control analysis is warranted. It is worth noting that the effect of deleting these crashes from the analysis will be that the travel speed - crash risk relationship will be attenuated.

Given the need to exclude these crashes from the Case-Control analysis, it is important to also identify ECIS Control drivers where AOD use was indicated.

AOD use among ECIS Control drivers

As part of the ECIS Control Arm process, observed drivers were sent a survey that related to the trip where their speed was recorded. This trip was referred to as the Index Trip (see *ECIS Report 1*, chapter 2 for detail). Drivers were asked a series of questions concerning the Index Trip, including the consumption of alcohol and illicit drug use. This retrospective approach was necessary as stopping each vehicle for the purposes of gaining informed consent to participate in the ECIS program was not feasible. It was therefore not possible to obtain an objective measure of alcohol consumption through a breath test or the use of illicit drugs that would require an oral fluid sample or blood sample from each driver. It was therefore necessary to rely on self-report, noting the limitations of this approach and the inability to determine any level of impairment whilst driving. Table 3.5 provides the number and percent of ECIS Control drivers who self-reported alcohol and/or the use of illicit drugs in the 2 hours and 12 hours prior to the Index Trip.

A total of 28 Control drivers (2.3%) self-reported AOD use. Most (n= 20) were associated with ECIS Lane Departure crashes (2.9%) and 8 were associated with ECIS Across Path crashes (1.5%) ($p \geq 0.05$). Hence, 97.7% of responding drivers stated that they had not consumed AOD in the preceding 2 hours and 12 hours, respectively, of the Index Trip (Lane Departure: 97.1%; Across Path: 98.5%). These 28 Control drivers were associated with 22 ECIS crashes.

TABLE 3.5 SELF-REPORTED CONSUMPTION OF ALCOHOL AND/OR ILLICIT DRUGS BY CONTROL DRIVERS

ALCOHOL AND OTHER DRUG SELF-REPORTED USE	ALL CONTROL DRIVERS (n = 1230)	ECIS CRASH TYPE	
		LANE DEPARTURE (n = 701)	ACROSS PATH (N = 529)
Alcohol use, within 2 hours vehicle observed			
Yes, consumed alcohol	2.0% (n = 24)	2.4% (n = 17)	1.3% (n = 7)
No, no alcohol consumed	98.0% (n = 1206)	97.6% (n = 684)	98.7% (n = 522)
Illicit drug use, within 12 hours vehicle observed			
Yes, consumed illicit drug(s)	0.3% (n = 4)	0.4% (n = 3)	0.2% (n = 1)
No illicit drug(s) consumed	99.7% (n = 1226)	99.6% (n = 698)	99.8% (n = 528)

With respect to alcohol consumption, 24 Control drivers self-reported consuming alcohol within 2 hours of the Index Trip, none of whom reported having used an illicit drug within 12 hours of the Index Trip. Of these, 17 were associated with Lane Departure crashes (2.4%) and seven were associated with Across Path crashes (1.3%) ($p \geq 0.05$). Where reported, one driver reported consuming three standard drinks, two drivers reported consuming two standard drinks, two drivers reported consuming 1.5 standard drinks and 14 drivers reported consuming one standard drink; five drivers did not report the number of standard drinks consumed.

Four drivers reported having used an illicit drug in the 12 hours preceding the Index Trip. Three drivers reported having consumed cannabis and one driver reported having used heroin. One driver reported having consumed alcohol in the 12 hours prior, in addition to cannabis. None of these four drivers self-reported having used alcohol within 2 hours of the Index Trip. Drivers were not asked about their consumption of illicit drugs within 2 hours of the Index Trip.

The travel speeds of Control drivers by self-reported AOD use are presented in Table 3.6. The proportion of AOD drivers exceeding the speed limit (17.9%) was similar to that of non-AOD drivers (17.0%) ($p \leq 0.9$), this being somewhat lower in both groups compared to non-AOD Case drivers (19.4%, Table 3.4).

This finding is in contrast to that seen amongst crash-involved drivers where AOD use was associated with exceeding the speed limit. This may reflect differences in AOD measurement, level of use (i.e., BAC level), as well as the difference in the proportion of Case drivers that had used illicit drugs (71.4%, n = 15 of 21) compared to Control drivers who self-reported illicit drug use where self-reporting bias and recall accuracy may present (14.3%, n = 4 of 28). Given these AOD measurement constraints and the small number of Control drivers indicating AOD use, caution ought to be exercised when interpreting the percent distribution of drivers exceeding the speed limit.

TABLE 3.6 TRAVEL SPEED FOR CONTROL DRIVERS SELF-REPORTING AOD USE AND THOSE REPORTING NO USE

TRAVEL SPEED	ALL DRIVERS (N = 1230)	AOD DRIVERS (N = 28)	NON-AOD DRIVERS (N = 1202)
At or below speed limit	83.0% (n = 1021)	82.1% (n = 23)	83.0% (n = 998)
Exceed speed limit	**17.0%† (n = 209)**	**17.9% (n = 5)**	**17.0%† (n = 204)**
By 1.0 – 4.9 km/h	9.9% (n = 122)	3.6% (n = 1)	10.1% (n = 121)
By 5.0 – 9.9 km/h	5.0% (n = 62)	10.7% (n = 3)	4.9% (n = 59)
By 10.0 + km/h	2.0% (n = 25)	3.6% (n = 1)	2.0% (n = 24)

† exceed speed sub-categories have rounding error of +0.1% with use of 1 decimal place.

ECIS crashes (Case data) used in the estimation of crash risk associated with travel speed

Given the association between exceeding the speed limit and AOD use, crashes where AOD use by an involved driver was indicated were removed from the analysis set. Likewise, Control drivers who self-reported AOD use were excluded from the analysis set. This step was taken to eliminate to the extent possible the potential confounding effect of the prior recent use of AOD.

With the removal of the 21 crashes where AOD use was indicated, the analysis set consists of 146 crashes. The number of crashes by type and the associated level of injury is presented in Table 3.7. The characteristics of these crashes are examined in detail in the *Results* section, however the high proportion of MAIS 3+ crashes are notable, as is the spread of crashes among the Lane Departure and Across Path crash sub-types.

TABLE 3.7 NUMBER AND INJURY SEVERITY OF ECIS CRASHES BY CRASH TYPE (EXCLUDING AOD)

CRASH TYPE	ECIS CRASHES†			CRASH SEVERITY‡					
				MAIS 1		MAIS 2		MAIS 3+	
All	**146**	**100%**	**-**	**24**	**16.4%**	**39**	**26.7%**	**83**	**56.8%**
Lane Departure	**80**	**54.8%**	**100%**	**11**	**13.8%**	**19**	**23.8%**	**50**	**62.5%**
Off-road: to left	22	15.1%	27.5%	6	27.3%	5	22.7%	11	50.0%
Off-road: to right	23	15.8%	28.8%	3	13.0%	9	39.1%	11	47.8%
Head-on: curve	13	8.9%	16.3%	0	0.0%	1	7.7%	12	92.3%
Head-on: straight	22	15.1%	27.5%	2	9.1%	4	18.2%	16	72.7%
Across Path	**66**	**45.2%**	**100%**	**13**	**19.7%**	**20**	**30.3%**	**33**	**50.0%**
Across path: enter	22	15.1%	33.3%	6	27.3%	8	36.4%	8	36.4%
Across path: turn across	14	9.6%	21.2%	2	14.3%	5	35.7%	7	50.0%
Across path: cross traffic	30	20.5%	45.5%	5	16.7%	7	23.3%	18	60.0%

† column percent; ‡ row percent.

While the same relationship between AOD use and travel speed was not observed among the Control drivers, these 28 drivers were also removed from the analysis. It is acknowledged that this is a conservative approach, particularly given that there was no direct evidence of impaired driving for those self-reporting AOD use. However, this decision was made on the basis of consistency with the approach taken to addressing AOD use among the Case drivers and the number of available Control drivers for each Case driver. Consideration was given to conducting an analysis that statistically adjusts for AOD consumption among relevant Case drivers and Control drivers, however given the differences in the measurement and reporting of AOD use, this was not performed.

3.2.4 Data analysis

As a first step a descriptive analysis of the proportion of drivers travelling at or below the speed limit and exceeding the speed limit was performed. This was done to provide an understanding of the nature of speed choice and to document the differences, if any, in the travel speed profile of the ECIS Case drivers and ECIS Control driver sample. Driver demographics were also examined with differences between ECIS Case drivers and ECIS Control drivers being assessed using chi-square tests,[45] t-tests[46,47] and ANOVA tests as appropriate. For ANOVA tests, post-hoc contrasts were corrected for Type I error using the Bonferroni adjustment.

The key analysis of interest was the assessment of the association between free travel speed and crash risk. Conditional logistic regression[48,49,50] was used for this analysis. Analysis was conducted for Lane Departure crashes and Across Path crashes combined and separately.

Taking advantage of the match Case-Control study design, Case-Control match sets were defined by the crash location and were treated as individual strata using the *group* STATA *clogit* command. With the travel speed of multiple Control vehicles being observed for each driver involved in a crash, this is referred to a 1-*M* design. While the goal was to include the travel speed of three Control drivers for each Case (i.e., crash-involved) driver, this number can differ. For multiple-vehicle crashes, measures for both crash vehicles and associated control vehicles were included within each crash strata.

Within each crash, Case and Control vehicles were matched on vehicle movement (i.e., turning, going straight) and direction. This means that the travel speed of vehicles travelling in the same direction and performing the same movement are being compared statistically, the difference being one vehicle was involved in a crash and the other(s) were not. This approach also ensures that the road environment, infrastructure, traffic volume and other traffic flow factors influencing travel speed of the Case and the Control vehicles are the same within each Case-Control pair. Hence these potential confounding but unmeasured factors are accounted for when estimating the relationship between travel speed and (hospitalisation-severity) crash risk.

The goal of the analysis was to estimate the relationship between travel speed and crash risk for crashes where a driver was hospitalised. In simple terms, the statistical modelling first uses the travel speed of the Case driver and each Control driver within each individual crash (i.e., pair) to estimate this risk. This risk is then essentially aggregated across all Case-Control match sets to arrive at the reported relationship between travel speed and crash risk. As the Case sample was drawn from hospitalised drivers, the crash risk is most accurately referred to as *hospitalisation-severity crash risk*.

Travel speed was modelled as a continuous variable using deviation from the speed limit (i.e., free travel speed minus the speed limit). In the model building process, the appropriateness of using free travel speed as a linear term was assessed using fractional polynomials as implemented in STATA.[51,52] The representation of travel speed using higher order power terms was assessed using FP1 (one power term, $\beta 1X^{p1}$) and FP2 (two power terms, $\beta 1X^{p1} + \beta 2X^{p2}$) models using the default power terms {-2, -1, -0.5, 0, 0.5, 1, 2, 3} where 0 = ln(X) and 1 is linear ('as is'). Model deviance was used to assess the appropriateness of travel speed being used in its linear form or as an alternative function; a p-value of < 0.05 with the relevant degrees of freedom (*df*) for χ^2 was set as the basis for the decision process on whether the travel speed was best represented as a linear term or an alternative representation; this was confirmed using the *fp select* command in STATA.[53] In this process, the travel speed value (relative to the speed limit) was transformed to meet the need for positive values in the fractional polynomial process. In each model, the functional form of the travel speed hospitalisation-severity crash risk relationship was best represented in a linear form. This means that in this dataset of 146 crashes and associated Control drivers the use of travel speed in its continuous form and without transformation provides the most parsimonious representation of the relationship between travel speed and crash risk. Using the travel speed data in its original ratio form also offers maximum discrimination which is important in the

45 Siegel S, Castellan NJ. Nonparametric Statistics for the Behavioural Sciences. New York: McGraw-Hill; 1988.
46 Mitchell MN. Stata for the Behavioural Sciences. College Station, TX: StataCorp LP; 2015.
47 Keppel G, Wickens T D. Design and analysis: A researcher's handbook. New Jersey: Pearson Prentice Hall; 2004.
48 Hosmer DW, Lemeshow, S. Applied logistic regression, Second Edition. New York: John Wiley and Sons; 2001.
49 Long JS, Freese J. Regression models for categorical dependent variables using Stata, Third Edition. College Station, TX: Stata Press; 2014.
50 Rabe-Hesketh S, Skrondal A. Multilevel and longitudinal modelling using Stata, Third Edition. College Station, TX: Stata Press; 2012.
51 Royston P, Altman DG. Regression using fractional polynomials of continuous covariates: Parsimonious parametric modelling (with discussion) Journal of the Royal Statistical Society, Series C. 1994;43:429–467.
52 Royston P, Sauerbrei W. Multivariable Model-building: A Pragmatic Approach to Regression Analysis Based on Fractional Polynomials for Modelling Continuous Variables. Chichester, UK: Wiley; 2008.
53 Royston P. Model selection for univariable fractional polynomials [select FP model]. Stata J. 2017;17(3):619-629.

determination of risk. Here, the reader is also referred to Kloeden and colleagues who noted a number of disadvantages when using categories to examine the association between travel speed and crash risk.[54]

The influence of co-variates (i.e., age, sex) was assessed using the change in Deviance between models with and without the co-variates of interest. These variables were included based on the model fit and their individual P-value as appropriate and the Likelihood Ratio test was used for this purpose. Both unadjusted (i.e., without age and sex as co-variates) and adjusted analysis (i.e., with age and sex as co-variates) was conducted and presented.

As an example of the data, theoretical travel speed data of three Control drivers measured at the scene of a single-vehicle crash is presented. The 'match set' is defined by the crash involved vehicle (Case) and the associated Control vehicle(s). The speed limit was 100 km/h. Driver age and sex is provided.

Crash	Vehicle	Direction	Manoeuvre	Matched Set	Travel speed (km/h)	Difference to speed limit (km/h)	Driver sex	Driver age
1	Case	North	Straight	1	105	+5	Male	18
1	Control	North	Straight		100	0	Male	22
1	Control	North	Straight		98	-2	Female	32
1	Control	North	Straight		99	-1	Female	52
…				…				
146				…				

In this example the crash-involved driver (Case) was travelling 5 km/h above the speed limit, with the three observed non-crash-involved drivers (Control) travelling at or below the speed limit. The statistical model uses this information across all Case-Control match sets to estimate the relationship between travel speed and crash risk. By including measured variables that differ between drivers (e.g., age, sex), any potential confounding associated with these factors can also be controlled for. Further, because the data are matched at each of the 146 crash sites with vehicles also being matched for travel direction and manoeuvre, it is not necessary to include other site-specific factors that may influence driver travel speed.

In all conditional logistic regression models the outcome of interest is the OR. The OR reflects the change in the log-odds for a one unit change in the covariate.[55,56] The model coefficients give the probability that the driver with data x_{k1} is the Case (i.e., in the crash) relative to (in this example) the three controls with data x_{k2}, x_{k3} and x_{k4}. Given the Case-Control design and the rare nature of crashes, the OR is used as an approximation of the relative risk (risk in exposed group vs. the risk in non-exposed group); this is also known as the Risk Ratio (RR).[55]

In this report the RR therefore estimates the relative crash risk; for ease, the term crash risk is used in this report noting this relates to hospitalisation-severity crashes. A RR of 1.0 indicates that there is no difference in the crash risk between the groups being compared (e.g., exceed speed limit vs. not), a RR of > 1.0 indicates an increased risk, and a RR < 1.0 indicates a decreased risk; 95% confidence intervals are also presented.[56,57] To aid interpretation, the RR is presented and described as x% increase / decrease in the risk of being involved in a crash (i.e., outcome) given vehicle travel speed relative to the speed limit. The RR reflects the strength and direction of the association between speed choice and crash involvement.

The Population Attributable Fraction (PAF) was calculated in relation to drivers exceeding the speed limit and crash outcomes. The PAF provides an estimate of the proportion of the total number of crashes that occurred due to drivers exceeding the speed limit. The PAF value is therefore the percentage of crashes that could be eliminated by ensuring 100% compliance with current speed limits. This outcome depends on the assumption that the association between crash involvement and speed-related behaviour is causal. With respect to crash occurrence, achieving the full PAF reduction value depends on the assumption that travel speed was the sole contributing factor for the crash; based on this assumption and with knowledge of the overlap in multiple contributing factors (see *ECIS Report 1*), the estimated PAF value is likely to be an overestimate of the benefit of 100% speed limit compliance. A further assumption is that co-variate characteristics are the same in the broader population. As a first step in calculating the PAF, conditional logistic regression with robust standard

54 Kloeden CN, McLean AJ. Glonek G. 2002. Reanalysis of travelling speed and the risk of crash involvement in Adelaide, South Australia. CR 207. Australian Transport Safety Bureau. Canberra, Australia.
55 Vittinghoff E, Glidden DV, Shiboski SC, McCulloch CE. Regression Methods in Biostatistics: Linear, Logistic, Survival and Repeated Measures Models. New York, NY: Springer; 2005.
56 Schlessellman JJ. Case-Control Studies: Design, Conduct and Analysis. New York: Oxford University Press, 1982.
57 du Prel JB, Hommel G, Röhrig B, Blettner M. Confidence Interval or P-Value? Dtsch Arztebl Int 2009; 106(19): 335–339.

errors was used with exceeding the speed limit defined as ≥ 1 km/h. The PAF value was calculated using the *punafcc* Stata module that accounts for the Case-Control design.[58]

Analysis was performed in SPSS v.26[59] and STATA v.16.[60] Statistical significance was set at $p \leq 0.05$.

3.3 RESULTS

This section presents the statistical analysis of the relationship between travel speed and crash risk. First, details of the number of crash-involved (Case) drivers and associated Control drivers, along with the age and sex profile of these drivers, are presented, as both variables were used in the statistical modelling of the relationship between travel speed and crash risk.

The number of crashes by speed zone and the injury severity profile of crashes are also provided. These data can be used to understand the generalisability of the reported findings. This is of value as the crashes included in the Case-Control analysis represent a subset of the overall ECIS sample that was the subject of *ECIS Report 1*.

With respect to the generalisability of the results, it is emphasised that the findings in relation to travel speed and crash risk are only applicable to crashes where an involved driver required hospitalisation for the treatment of injuries sustained in a crash. The term 'crash risk' is used in this report for the sake of brevity but must be interpreted within these parameters. This is alternatively expressed as hospitalisation-severity crash risk in this report.

Further, and as described in the *Method* (Section 3.2), the relationship between travel speed and crash risk was examined by using travel speed as a continuous variable centred to the speed limit. Therefore, the results are presented as the crash risk relative to travelling at the speed limit. Driver age and/or driver sex were included in the analysis models where statistically indicated.

3.3.1 Number and demographic profile of drivers in the Case-Control analysis set

There were 247 drivers involved in the 146 crashes (A-vehicle: 146; B-vehicle: 101 drivers). The matched Control driver sample consisted of 1,039 drivers (A-vehicle Control drivers: 628; B-vehicle Control drivers: 411) (Table 3.8).

TABLE 3.8 NUMBER OF DRIVERS INVOLVED IN ECIS CRASHES AND ASSOCIATED CONTROL DRIVERS

ECIS CASE-CONTROL DRIVER TYPE	ALL CRASH TYPES	CRASH TYPE	
		LANE DEPARTURE	ACROSS PATH
ECIS Case (A-vehicle) drivers	**146**	**80**	**66**
A-vehicle Control	628	370	258
A-vehicle Control : Case ratio	4.3:1	4.6:1	3.9:1
ECIS B-vehicle drivers	**101**	**35**	**66**
B-vehicle Control	411	173	238
B-vehicle Control : Case ratio	4.1:1	4.9:1	3.6:1
ECIS Case drivers (A | B)	**247**	**115**	**132**
A | B Control	1039	543	496
A | B Control : Case ratio	4.2:1	4.7:1	3.8:1

The ratio of Control drivers to Case drivers was 4.2 overall, with this being 4.3:1 for A-vehicle drivers and 4.1:1 for B-vehicle drivers. This compares favourably with the goal at the commencement of the ECIS program of obtaining a control-to-case ratio of at least 3.0:1 (see Section 3.2.3.1 for discussion of this ratio).

For completeness, it is noted that for six crashes both drivers (n = 12) involved in the crash were enrolled as ECIS Case drivers. For these crashes, the driver first enrolled to the ECIS Case Study was nominated as the

58 Newson RB. Attributable and unattributable risks and fractions and other scenario comparisons. Stata J 2013;13:672-98.
59 IBM. SPSS Statistics, v.25 [computer program]. IBM Corp. IBM SPSS Statistics for Windows, Version 25.0.[computer program] Armonk, NY: IBM Corp; 2017.
60 StataCorp. Stata MP Version 15 [computer program]. College Station, TX: StataCorp; 2017.

A- vehicle driver with the subsequent driver enrolled being the B-vehicle driver for the purposes of the Case-Control analysis. Three were Lane Departure crashes and three were Across Path crashes.

The age and sex profile of the ECIS Case drivers and the ECIS Control drivers is presented in Table 3.9. Overall, 57.5% of ECIS Case drivers were male and 42.5% were female. In contrast, 50.1% of ECIS Control drivers were male and 49.9% were female ($p \leq 0.05$).

TABLE 3.9 DEMOGRAPHIC CHARACTERISTICS OF CASE DRIVERS AND CONTROL DRIVERS

	ECIS CASE			ECIS CONTROL		
DEMOGRAPHIC CHARACTERISTIC	A – B VEHICLE† (N = 247)	A-VEHICLE† (N = 146)	B-VEHICLE† (N = 101)	A – B VEHICLE† (N = 1039)	A-VEHICLE† (N = 628)	B-VEHICLE† (N = 474)
SEX						
Male	57.5% (n = 142)	47.3% (n = 69)	72.3% (n = 73)	50.1% (n = 521)	50.6% (n = 318)	49.4% (n = 203)
Female	42.5% (n = 105)	52.7% (n = 77)	27.7% (n = 28)	49.9% (n = 518)	49.4% (n = 310)	50.6% (n = 208)
AGE (YEARS)						
Mean (SD)	49.9 (20.5)	53.5 (21.4)	44.4 (17.9)	49.3 (15.8)	48.9 (15.6)	49.9 (15.9)
Median	49.0	55.5	43.0	49.6	49.0	51.0
Range	16 - 93	18 - 92	16 - 93	17 - 93	17 - 93	18 - 88
AGE CATEGORY (YEARS)						
18 - 25	16.2%§ (n = 40)	16.4% (n = 24)	15.8% (n = 16)	7.8%∞ (n = 81)	7.3%∞ (n = 46)	8.5% (n = 35)
26 - 39	19.0% (n = 47)	13.7% (n = 20)	26.7% (n = 27)	21.0% (n = 218)	22.5% (n = 141)	18.7% (n = 77)
40 - 59	29.6% (n = 73)	25.3% (n = 37)	35.6% (n = 36)	41.5% (n = 431)	41.4% (n = 260)	41.6% (n = 171)
60 - 75	21.5% (n = 53)	25.3% (n = 37)	15.8% (n = 16)	26.2% (n = 272)	25.5% (n = 160)	27.3% (n = 112)
76 +	13.8% (n = 34)	19.2% (n = 28)	5.9% (n = 6)	3.6% (n = 37)	3.3% (n = 21)	3.9% (n = 16)

† % by column; § includes one 16-year-old driver and one 17-year-old driver (B-vehicle); ∞ includes one 17-year-old driver (Control-A).

The proportions of male and female A-vehicle Case and Control drivers were similar (Case-A Male: 47.3%; Control-A Male: 50.6%); however, of the B-vehicle Case drivers there were more males (72.3%) than were present in the Control-B vehicle set (49.4%) ($p \leq 0.05$). In interpreting this difference, it is important to first understand that A-vehicle drivers were ECIS Case drivers enrolled to the study following admission to one of the study hospitals, and that this 'A-B' classification does not reflect fault or responsibility for the crash.

That there were a higher proportion of males as B-vehicle Case drivers than A-vehicle Case drivers (and B-vehicle Control drivers) is of interest as it may reflect ECIS Case sampling and/or crash-related factors. With respect to ECIS Case sampling, the participation rate (M: 43%; F: 47%) and consent rate (M: 65%; F: 68%) for males and females was similar (see *ECIS Report 1*, Appendix B). Related to this is that females accounted for 49.7% of the 7,628 TAC Hospitalisation driver claims for the period of ECIS (mid-2014 to end 2016) and 50.1% were from male drivers.[61] By inference, the proportion of A-vehicle and B-vehicle male and female Case drivers ought to be similar. It *may* be the case then that crash and/or vehicle-related factors may explain this difference including for instance crash configuration, impact point, and the type of vehicle and its associated crashworthiness or aggressivity. Other driver factors, including behavioural factors, could also play a role in explaining this difference. Injury severity differences between drivers may also explain this sex difference,

61 See: https://www.tac.vic.gov.au/road-safety/statistics/online-crash-database/search-crash-data

particularly if crash-involved drivers were either transported to a hospital other than The Alfred Hospital and The Royal Melbourne Hospital, sustained minor injury and were not transported to hospital, or were uninjured in the crash. Other factors, including pre-hospital triage protocols and hospital availability may also have played a role. It is more likely however to be a combination of factors rather than a single explanation and further work is required to understand the source of this difference. Irrespective of the reason for this difference, the presence of this difference means that it is necessary to assess for, and adjust, if necessary, the potential confounding influence of driver sex on the relationship between travel speed and crash risk.

The mean age of ECIS Case drivers (A, B) (Mean = 49.9 years)[62] and ECIS Control drivers (A, B) was similar (Mean = 49.3 years). However, the mean age of A-vehicle Case drivers (Mean = 53.5 years) was older than A-vehicle Control drivers (48.9 years) ($p = 0.01$). In addition, B-vehicle Case drivers were on average younger (Mean = 44.4 years) than B-vehicle Control drivers (Mean = 49.9 years) ($p \leq 0.05$). B-vehicle Case drivers were also younger than A-vehicle case drivers ($p \leq 0.05$). These differences may reflect sampling, crash-related, and/or injury severity factors described above in relation to driver sex. As with differences in driver sex it is necessary to assess for, and statistically account for the effect of any confounding effect of driver age when modelling the association between travel speed and crash risk.

The age distribution of the ECIS Case drivers and ECIS Control drivers differed ($p \leq 0.05$) with a higher proportion of drivers 18 – 25 years of age and drivers 76 years of age and older–particularly A-vehicle drivers– in the ECIS Case driver sample than the ECIS Control sample. While this result may reflect ECIS Control sample response bias, the increased involvement of these two age groups in hospitalisation-severity crashes is well understood.

3.3.2 Speed zone and injury severity of ECIS crashes in the Case-Control analysis set

The speed zone and injury severity of the ECIS crashes included in the Case-Control analysis set are presented in Table 3.10. Crashes occurred within each speed zone although 35.6% (n = 52) occurred in a 100 km/h speed zone, 26.7% (n = 39) occurred in a 60 km/h speed zone and 21.9% (n = 32) occurred in 80 km/h speed zones. Differences were evident in the location of crashes between Lane Departure crashes and Across Path crashes.

Overall, 56.8% of crashes involved one or more occupants sustaining MAIS 3+ injuries (56.8%, n = 83) (Table 3.11). A higher proportion of Lane Departure crashes (62.5%, n = 50) resulted in MAIS 3+ injuries than did Across Path crashes (50.0%, n = 33), although this difference was not statistically significant ($p = 0.3$).

TABLE 3.10 SPEED ZONE AND INJURY SEVERITY OF CRASHES INCLUDED IN THE CASE-CONTROL ANALYSIS

CHARACTERISTIC	ALL CRASH TYPES (n = 146)	CRASH TYPE	
		LANE DEPARTURE (n = 80)	ACROSS PATH (N = 66)
SPEED LIMIT (HIGHEST USED WHERE CRASH AT INTERSECTION)			
≤ 50 km/h	4.8% (n = 7)	5.0% (n = 4)	4.5% (n = 3)
60 km/h	26.7% (n = 39)	17.5% (n = 14)	37.9% (n = 25)
70 km/h	8.9% (n = 13)	8.8% (n = 7)	9.1% (n = 6)
80 km/h	21.9% (n = 32)	17.5% (n = 14)	27.3% (n = 18)
90 km/h	0.7% (n = 1)	1.3% (n = 1)	0.0% (n = 0)
100 km/h	35.6% (n = 52)	47.5% (n = 38)	21.2% (n = 14)
110 km/h	1.4% (n = 2)	2.5% (n = 2)	0.0% (n = 0)
CRASH SEVERITY			
MAIS 1	16.4% (n = 24)	13.8% (n = 11)	19.7% (n = 13)
MAIS 2	26.7% (n = 39)	23.8% (n = 19)	30.3% (n = 20)
MAIS 3+	56.8% (n = 83)	62.5% (n = 50)	50.0% (n = 33)

62 For comparison, the demographic profile of the overall ECIS Case driver sample was: 55.8% male, 44.2% female; mean age of drivers was 49.4 years (Median = 48.5; Range = 18 – 93 years) and the mean and median age of male drivers and female drivers were similar. Age categories: 18 – 25 years: 18.3%; 26 – 39 years: 19.8%; 40 - 59 years: 26.7%; 60 – 75 years: 21.7%; 76 years older: 13.5%.

Other crash location, road class, crash type and vehicle age characteristics are presented in Appendix D (Table D.1, Table D.2).

3.3.3 Speed choice, travel speed relative to the speed limit and the calculation of hospitalisation-severity crash risk

To estimate crash risk, the travel speed of drivers involved in crashes (Case drivers) was compared to the travel speed of drivers not involved in crashes (Control drivers). As travel speed is influenced by site-specific factors, including road infrastructure, road class, the speed limit, traffic volume, the vehicle mix, and other driver-specific factors, it is necessary to match the crash-involved (Case) and non-crash-involved vehicles (Control) when performing the travel speed – crash calculation. Doing so provides two additional advantages: 1) the vehicle movement (i.e., direction, manoeuvres) is matched, and 2) because the vehicle speed is a product of site-specific factors, the contribution of these factors to the crash are controlled for automatically. Due to these design and speed measurement factors, to obtain an appropriate estimate of crash risk specific statistical procedures that account for the Case-Control design (i.e., matching) are required. Following this point, it is not appropriate to use the aggregated data to calculate crash risk.

It is however of interest to document the percent and number of Case drivers and Control drivers travelling at or below the speed limit and exceeding the speed limit (Table 3.11). Given the comments above, no statistical tests comparing the percentage of drivers exceeding the speed limit between the Case and Control samples are presented. Rather, the data are presented here for descriptive purposes only and for reasons of transparency. Further data are provided in Appendix D.

The majority of Case drivers (81.4%) and Control drivers (84.8%) were travelling at or below the speed limit. Slightly more Case drivers (18.6%) than Control drivers (15.2%) were exceeding the speed limit, while the proportions of Case drivers and Control drivers exceeding the speed limit by less than 5.0 km/h and 5.0 – 9.9 km/h were similar. Few drivers exceeded the speed limit by greater than 10 km/h, a result that reflects a high compliance culture with speed limits in Victoria. The proportion of drivers exceeding the speed limit was higher in the Lane Departure crashes (27.0%) compared to drivers involved in Across Path crashes (11.4%) ($p \le 0.05$).

TABLE 3.11 TRAVEL SPEED OF CASE AND CONTROL DRIVERS (VEHICLES) RELATIVE TO THE SPEED LIMIT

TRAVEL SPEED	ALL CRASH TYPES	CRASH TYPE	
		LANE DEPARTURE	ACROSS PATH
CASE DRIVERS (A / B VEHICLE)			
At or below speed limit	81.4% (n = 201)	73.0% (n = 84)	88.6% (n = 117)
Exceed speed limit	**18.6% (n = 46)**	**27.0% (n = 31)**	**11.4% (n = 15)**
By 1.0 – 4.9 km/h	9.7% (n = 24)	13.9% (n = 16)	6.1% (n = 8)
By 5.0 – 9.9 km/h	4.5% (n = 11)	7.0% (n = 8)	2.3% (n = 3)
By 10.0 – 14.9 km/h	2.4% (n = 6)	1.7% (n = 2)	3.0% (n = 4)
By 15.0 + km/h	2.0% (n = 5)	4.3% (n = 5)	0.0% (n = 0)
CONTROL DRIVERS (A / B VEHICLE)			
At or below speed limit	84.8% (n = 881)	77.5% (n = 421)	92.7% (n = 460)
Exceed speed limit	**15.2% (n = 158)**	**22.5% (n = 122)**	**7.3% (n = 36)**
By 1.0 – 4.9 km/h	9.4% (n = 98)	13.1% (n = 71)	5.4% (n = 27)
By 5.0 – 9.9 km/h	4.1% (n = 43)	6.8% (n = 37)	1.2% (n = 6)
By 10.0 – 14.9 km/h	0.9% (n = 9)	1.5% (n = 8)	0.2% (n = 1)
By 15.0 + km/h	0.9% (n = 8)	1.1% (n = 6)	0.4% (n = 2)

3.3.4 The association between travel speed and hospitalisation-severity crash risk

This section examines the relationship between travel speed and the relative risk of being involved in a crash where a driver was hospitalised. This is examined for Lane Departure and Across Path crashes combined and separately. The derived crash risk estimates relate to crashes resulting in high levels of injury where one or more involved driver of a passenger vehicle required hospitalisation at a trauma centre; hence, these results are generalisable to crashes within these parameters. For simplicity, the term 'crash risk' refers to hospitalisation-severity crashes and the results of all analysis must be interpreted as such.

The analysis uses travel speed as a continuous variable and takes advantage of the Case-Control design that ensures that the travel speed of a vehicle(s) is compared to the travel speed of non-crash-involved vehicles at the same site, travelling in the same direction on the same day of the week and in the same period of the day. The statistical model is therefore able to estimate the relative crash risk at 1 km/h increments across the full speed range above and below the speed limit.

3.3.4.1 Unadjusted analysis

Using conditional (fixed effects) logistic regression, the association between vehicle travel speed and being involved in a crash where at least one vehicle driver was hospitalised was assessed. This model did not include driver age or driver sex as co-variates and is referred to as an unadjusted analysis.

Table 3.12 and Figure 3.2 present crash involvement relative risk, or risk ratio (RR), estimates for drivers travelling above and below the speed limit in 5 km/h increments; Figure 3.3 presents the RR estimates as the percent increase or percent decrease in the risk of being involved in a hospitalisation severity crash.

The analysis demonstrated that travel speed was associated with hospitalisation-severity crash risk and this relationship was statistically significant ($p < 0.001$). The analysis estimates that for every 1 km/h travelling above the speed limit, the relative risk of being involved in a hospitalisation-severity crash increases by 7.8% (RR: 1.08, 95% CI: 1.06 – 1.10).

Driving in excess of the speed limit was associated with a higher crash risk. For example, for low level speeding – defined as driving 3 km/h above the speed limit – the increased risk was estimated to be 25%; the 95% confidence intervals estimate that this increased risk could be as low as 19% or as high as 32% (RR: 1.25, 95% CI: 1.19 – 1.32).

As shown below, drivers travelling 5 km/h above the speed limit had a 1.45 times higher crash risk than drivers travelling at the speed limit; this equates to a 45.4% increase in crash risk associated with exceeding the speed limit by 5 km/h (95% CI Range = +32.7% to +59.4%; RR: 1.45, 95% CI: 1.33–1.59). For drivers travelling 10 km/h above the speed limit, their crash risk was more than double (i.e., twice) that of drivers travelling at the speed limit (+111.4%; RR: 2.12, 95% CI: 1.76–2.54). Driving 15 km/h above the speed limit was associated with a very high crash risk (+207.6%; RR: 3.08, 95% CI: 2.34–4.05).

The protective effect of driving below the speed limit was also evident with, for example, drivers travelling 5 km/h below the speed limit having a 31% lower risk of being involved in a hospitalisation severity crash (RR: 0.69, 95% CI: 0.63 – 0.76). The protective effect of travelling below the speed limit was greater with lower travel speeds. For instance, the crash involvement risk was 52.7% lower for drivers travelling 10 km/h (RR: 0.47, 95% CI: 0.39–0.57) and 67.5% lower for drivers travelling 15 km/h below the speed limit (RR: 0.33, 95% CI: 0.25–0.43).

TABLE 3.12 CRASH INVOLVEMENT RISK RATIO (RR) AND 95% CONFIDENCE INTERVALS RELATIVE TO DRIVING AT THE SPEED LIMIT, UNADJUSTED ANALYSIS

TRAVEL SPEED RELATIVE TO DRIVING AT THE SPEED LIMIT (KM/H)	RR	95% CI	
		LOWER	UPPER
-15	0.33	0.25	0.43
-10	0.47	0.39	0.57
-5	0.69	0.63	0.75
0	1.00	-	-
5	1.45	1.33	1.59
10	2.12	1.76	2.54
15	3.08	2.34	4.05

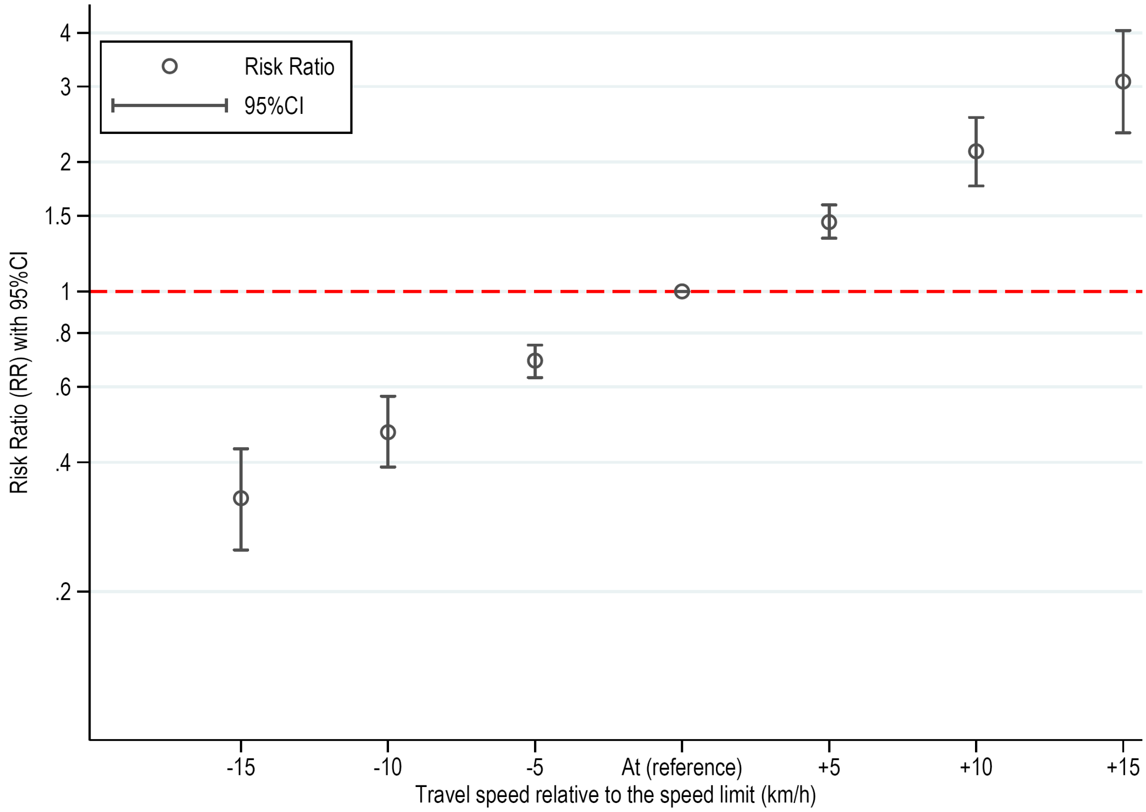

FIGURE 3.2 CRASH RISK RATIO (RR) ESTIMATES AND 95% CI VALUES FOR TRAVELLING ABOVE / BELOW THE SPEED LIMIT RELATIVE TO DRIVING AT THE SPEED LIMIT (LOG SCALE), UNADJUSTED ANALYSIS

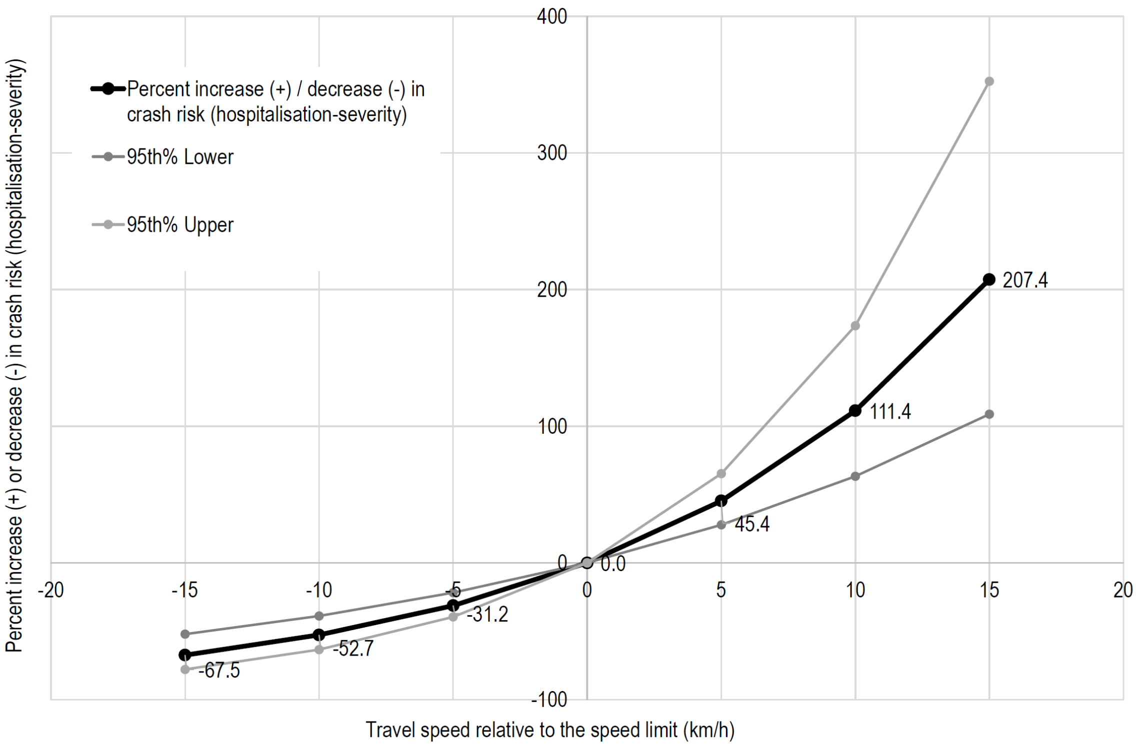

FIGURE 3.3 INCREASE (+) / DECREASE (-) IN HOSPITALISATION-SEVERITY CRASH RISK RELATIVE TO DRIVING AT THE SPEED LIMIT, UNADJUSTED ANALYSIS

3.3.4.2 Adjusted analysis with the inclusion of driver age and sex

Analysis supported the inclusion of driver age and driver sex into the statistical model. Both driver age and driver sex were strongly associated with Case status; that is, being involved in a crash that resulted in hospitalisation (Table 3.13). The influence of this on the association of travel speed and crash risk was however minimal.

Table 3.14 and Figure 3.4 present crash involvement relative risk, or RR estimates for drivers travelling above and below the speed limit in 5 km/h increments; Figure 3.5 presents the RR estimates as the percent increase or percent decrease in the risk of being involved in a hospitalisation severity crash.

Accounting for driver age and driver sex and excluding crashes and drivers where alcohol and/or illicit drugs had been used, travel speed was associated with *crash risk* — defined as hospitalisation-severity crashes – and this association was statistically significant ($p < 0.001$). It can be stated that:

1. For every 1 km/h travelling above the speed limit, the relative risk of being involved in a hospitalisation- severity crash increases by 7.6%, adjusted for driver age and driver sex (RR: 1.08, 95% CI: 1.06 – 1.10, $p < 0.001$).
2. Driving in excess of the speed limit was associated with a higher crash risk. For example, for low level speeding – defined as driving 3 km/h above the speed limit – the increased crash risk was estimated to be 25%; the 95% confidence intervals estimate that this increased risk could be as low as 18% or as high as 32% (RR: 1.25, 95% CI: 1.18 – 1.32).

   Drivers travelling 5 km/h above the speed limit had a 1.44 times higher crash risk than that of drivers travelling at the speed limit; this equates to a 44.4% increased crash risk (95% CI Range = +31.1% to +59.4%; RR: 1.44, 95% CI: 1.31–1.59). Hence, driving at 5 km/h above the speed limit was associated with a 44.4% increase in crash risk compared to driving the speed limit.

   For drivers travelling 10 km/h above the speed limit the crash risk was more than double (i.e., twice) that of drivers travelling at the speed limit (+108.5%; RR: 2.09, 95% CI: 1.72–2.53). Driving 15 km/h above the speed limit was associated was associated with a crash risk triple that of drivers travelling at the speed limit (+201.1%; RR: 3.01, 95% CI: 2.26–4.01).
3. The protective effect of driving below the speed limit was also evident with, for example, drivers travelling 5 km/h below the speed limit having a 30.8% lower risk of being involved in a hospitalisation severity crash (RR: 0.69, 95% CI: 0.63 – 0.76).

   The protective effect of travelling below the speed limit was greater with travel speeds further below the speed limit. For instance, the crash involvement risk was 52.0% lower for drivers travelling 10 km/h (RR: 0.48, 95% CI: 0.40–0.58) and 67.5% lower for drivers travelling 15 km/h below the speed limit (RR: 0.33, 95% CI: 0.25–0.44).

TABLE 3.13 CRASH INVOLVEMENT RISK RATIO (RR) AND 95% CONFIDENCE INTERVALS, ADJUSTED FOR DRIVER AGE AND SEX

PARAMETER	UNIT / CATEGORY	RR	95% CI		P-value
			LOWER	UPPER	
Travel speed	Per 1 km/h	1.08	1.06	1.10	<0.001
Driver sex					
	Female	Reference			
	Male	1.32	0.96	1.83	0.09
Driver age					
	18 – 25 years	Reference			
	26 – 39 years	0.39	0.22	0.70	0.002
	40 – 59 years	0.41	0.24	0.71	0.001
	60 – 75 years	0.49	0.27	0.87	0.015
	76+ years	3.03	1.39	6.59	0.005

TABLE 3.14 CRASH INVOLVEMENT RISK RATIO (RR) AND 95% CONFIDENCE INTERVALS RELATIVE TO DRIVING AT THE SPEED LIMIT, ADJUSTED FOR DRIVER AGE, DRIVER SEX

TRAVEL SPEED RELATIVE TO DRIVING AT THE SPEED LIMIT (KM/H)	RR	95% CI	
		LOWER	UPPER
-15	0.33	0.25	0.44
-10	0.48	0.40	0.58
-5	0.69	0.63	0.76
0	1.00	-	-
5	1.44	1.31	1.59
10	2.09	1.72	2.53
15	3.01	2.26	4.01

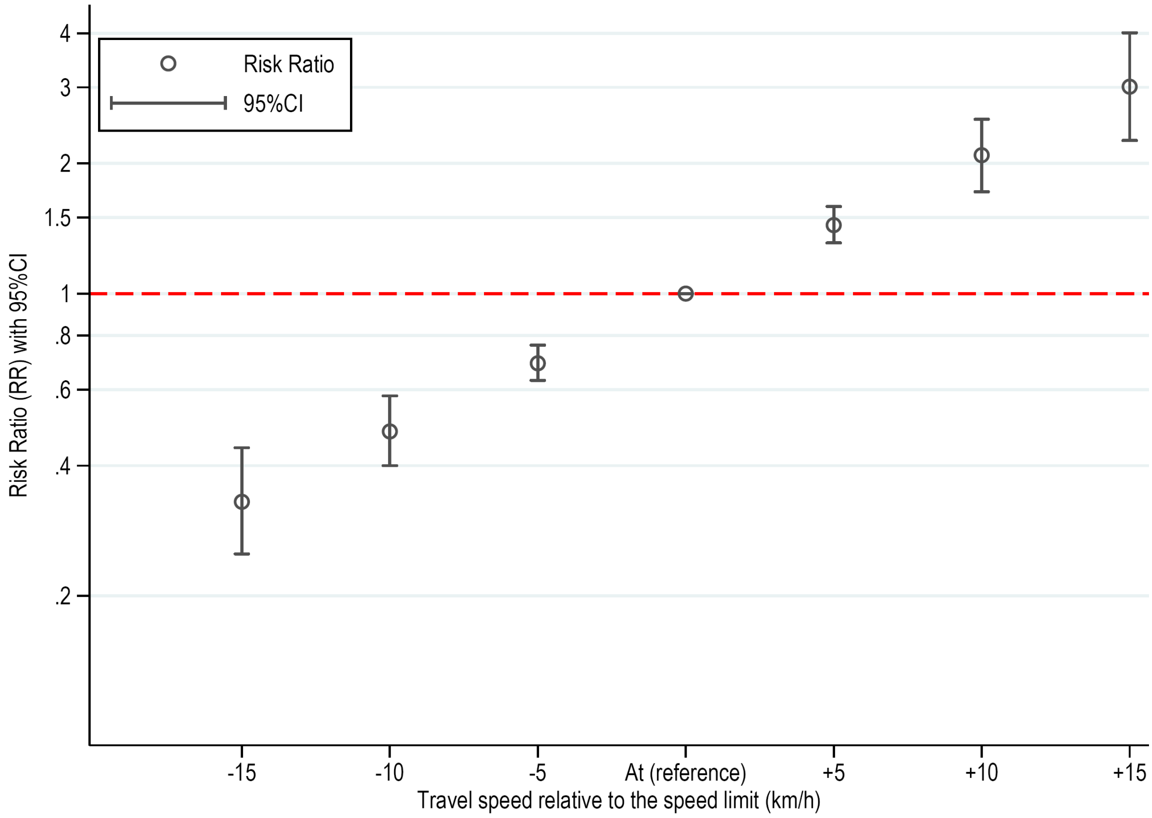

FIGURE 3.4 CRASH RISK RATIO (RR) ESTIMATES AND 95% CI VALUES FOR TRAVELLING ABOVE / BELOW THE SPEED LIMIT RELATIVE TO DRIVING AT THE SPEED LIMIT (LOG SCALE), ADJUSTED FOR DRIVER AGE AND SEX

While there was little difference in the magnitude of the association between travel speed and crash risk and the relative risk estimates between the unadjusted and adjusted statistical model, reference to the adjusted model results is preferred due to the added value of understanding the crash risk associated with driver sex and driver age.

With respect to driver sex, the analysis also showed that males had an indicative 32% higher risk than females of being a 'Case'; that is, of being involved in a crash, however this was not statistically significant (RR: 1.32, 95% CI: 0.96 – 1.83, p = 0.09) (Table 2.13). Driver sex was retained in the statistical model due to well-established relationships with crash risk in previous research and the interest in examining relevant risk factors in the ECIS program. Inclusion of driver sex had no influence on the magnitude of the RR for travel speed. No statistical interaction between driver age and driver sex was evident.

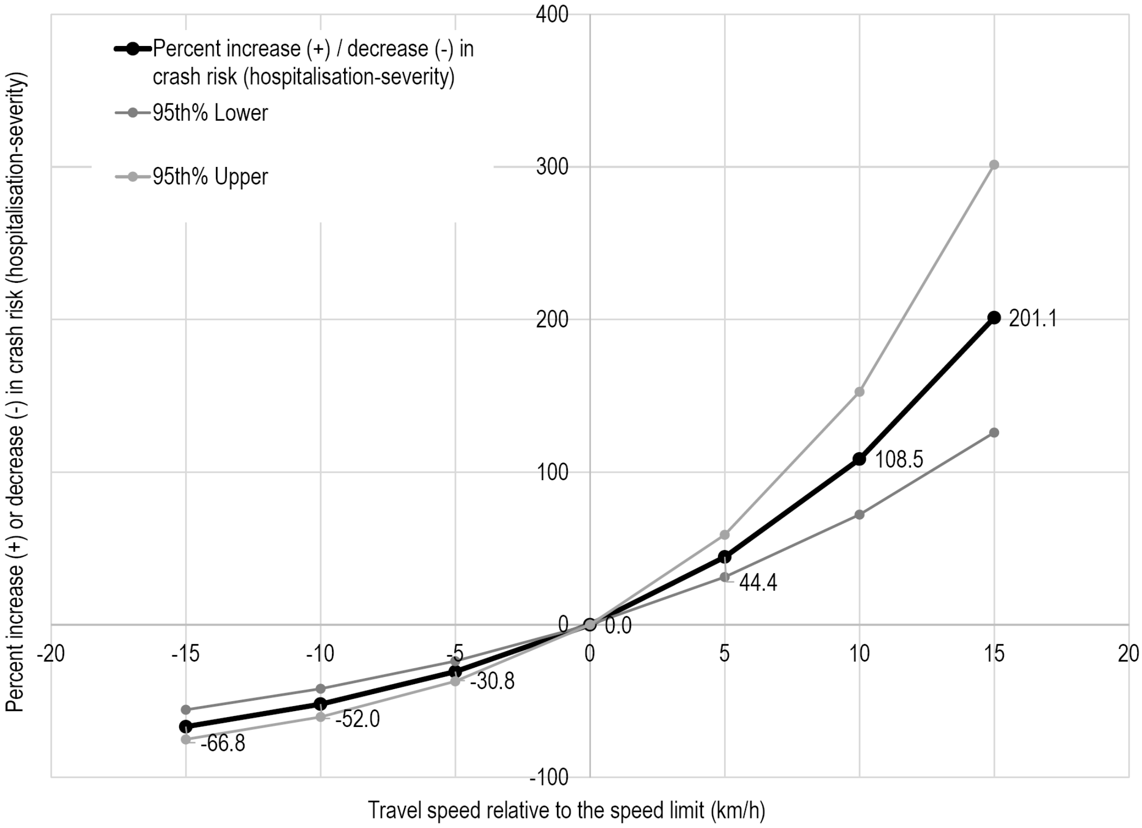

FIGURE 3.5 INCREASE (+) / DECREASE (-) IN HOSPITALISATION-SEVERITY CRASH RISK RELATIVE TO DRIVING AT THE SPEED LIMIT, ADJUSTED FOR DRIVER AGE AND SEX

Age group contrasts for drivers aged 18 – 25 years and 76+ years are provided in Table 3.15. The findings demonstrate an increased crash risk for these two groups relative to other age groups, noting the lower crash risk of drivers aged 18 – 25 years relative to drivers aged 76+ years.

TABLE 3.15 AGE GROUP CONTRASTS: CRASH INVOLVEMENT RISK RATIO (RR) AND 95% CONFIDENCE INTERVALS

AGE GROUP	RR	95% CI		P-VALUE
		LOWER	UPPER	
Driver age contrasts: focus on drivers 18 – 25 years of age				
18 – 25 years of age relative to 26 – 39 years	2.56	1.43	4.57	0.002
18 – 25 years of age relative to 40 – 59 years	2.42	1.41	4.17	0.001
18 – 25 years of age relative to 60 – 75 years	2.04	1.14	3.64	0.02
18 – 25 years of age relative to 76+ years	0.33	0.15	0.72	0.005
Driver age contrasts: focus on drivers 76+ years of age				
76+ years of age relative to 18 – 25 years	3.03	1.39	6.59	0.005
76+ years of age relative to 26 – 39 years	7.74	3.74	16.02	<0.001
76+ years of age relative to 40 – 59 years	7.34	3.71	14.50	<0.001
76+ years of age relative to 60 – 75 years	6.19	3.06	12.53	<0.001
Other driver age contrasts				
40 – 59 years relative to 26 – 39 years	1.06	0.66	1.68	0.8
60 – 75 years relative to 26 – 39 years	1.25	0.74	2.10	0.4
60 – 75 years relative to 40 – 59 years	1.19	0.76	1.84	0.5

Drivers aged 76 years and older were at an especially high risk of being involved in a hospitalisation-severity crash relative to drivers aged 18 – 25 years having a relative crash involvement risk three times higher (RR: 3.03, 95% CI: 1.39 – 6.59, p = 0.01). Drivers aged 18 – 25 years had a 2.56 times higher risk of being involved in a hospitalisation-severity crash than drivers aged 26 – 39 years (RR: 2.56, 95% CI: 1.43 – 4.57, p =0.002), 2.4 times that of drivers aged 40 – 59 years (RR: 2.42, 95% CI: 1.41 – 4.17, p =0.001) and twice that of drivers aged 60 – 75 (RR: 2.04, 95% CI: 1.14 – 3.64, p =0.01).

There was no difference in the hospitalisation-severity crash risk of drivers aged 26 – 39 years compared to drivers aged 40 – 59 years (p = 0.8) or drivers aged 60 – 75 years (p = 0.4). The hospitalisation-severity crash risk did not differ between drivers aged 40 – 59 years and drivers aged 60 – 75 years (p = 0.5).

3.3.4.3 Estimating the crash reduction benefit of eliminating speed limit non-compliance (i.e., speeding)

The Population Attributable Fraction (PAF) was calculated in order to estimate the percent of hospitalisation crashes that could be eliminated by achieving 100% compliance with current speed limits. In the unadjusted statistical model, the PAF was 7.5% while in the driver age – driver sex adjusted statistical model the PAF was 7.9%.

The results highlight that after accounting for the effects of driver age and driver sex, a 7.9% reduction in hospitalisation crashes of the type included in this sample could be achieved by eliminating speeding behaviour (i.e., exceeding the speed limit), noting the assumptions stated in the *Method* (Section 3.3.4).

3.3.4.4 Summary of findings

The analysis highlights a robust association between travel speed choice and crash risk. That is, the risk of being involved in a hospitalisation-severity crash is higher when exceeding the speed limit than when driving at the speed limit.

For instance, driving 3 km/h above the speed limit was associated with a 25% higher (or increased) crash risk than when driving at the speed limit, whilst travelling at 5 km/h above the speed limit was associated with a 44.4% higher crash risk relative to driving at the speed limit (RR: 1.44, 95% CI: 1.31 – 1.59).

The protective effect of driving below the speed limit was also evident with, for example, drivers travelling 5 km/h below the speed limit having a crash risk 0.69 that of drivers travelling at the speed limit. This can be interpreted as drivers traveling 5 km/h below the speed limit having a crash involvement risk 69% that of drivers travelling at the speed limit, equating to a 30.8% lower risk of being involved in a hospitalisation severity crash (RR: 0.69, 95% CI: 0.63 – 0.76).

These findings have considerable implications for road safety, and, in particular, point to countermeasures focussed on promoting and ensuring compliance with the speed limit. An estimated 7.9% reduction in hospitalisation crashes could be achieved by eliminating speed limit non-compliance. This percent reduction represents the average effect across Lane Departure crashes and Across Path crashes of the type included in the analysis set and may differ across speed zones.

Driver age and driver sex were also found to be associated with crash involvement. Male drivers and drivers 76+ years and older and drivers aged 18 – 25 years had a higher crash risk than females and drivers in the middle age band. Additional focus on these age groups with a view to reducing their crash risk is warranted.

These results are most applicable to crashes where one or more of the involved drivers was hospitalised, also noting that more than half of the crashes (57%) resulted in an MAIS 3+ injury to an involved driver and/or occupant. It is acknowledged that the risk estimates are a function of the travel speed and characteristics of the Control drivers who completed and returned the ECIS Control Survey to Monash University.

3.3.5 Lane Departure crashes: The association between travel speed and hospitalisation-severity crash risk

This section examines the association between travel speed and crash risk for Lane Departure crashes. These crashes comprise run-off-road crashes and head-on crashes. A total of 80 Lane Departure crashes formed the basis of the analysis. This section adopts the same presentation format and analysis method used in the estimation of crash risk where all crashes were used (Section 3.3.4).

3.3.5.1 Demographic profile of ECIS Case drivers involved in Lane Departure crashes and associated Control drivers

The age and sex profile of the ECIS Case drivers involved in Lane Departure crashes and the associated ECIS Control drivers is presented in Table 3.16. For these Lane Departure crashes 64.3% of ECIS Case drivers were male and 35.7% were female. In contrast, 49.7% of ECIS Control drivers were male and 50.3% were female (p ≤ 0.05). There was a higher proportion of male ECIS Case B-Vehicle drivers (80.0%) compared to ECIS Case A-vehicle drivers (57.5%) (p ≤ 0.05) while the proportions of male and female A-vehicle and B-vehicle Control drivers were largely similar (p > 0.05). The reader is referred to Section 3.1.1 for a discussion of the potential basis for this difference and the need to examine the influence of driver sex on the relationship between travel speed and crash risk, in addition to whether crash risk was seen to differ between male and female drivers.

The mean age of ECIS Case drivers (A, B) (Mean = 48.2 years)[63] was similar to the ECIS Control drivers (A, B) (Mean = 49.1 years) ($p = 0.5$). The mean age of drivers was similar across A-vehicle Case drivers (Mean = 49.1 years), B-vehicle Case drivers (Mean = 46.1 years), A-vehicle Control drivers (Mean= 49.2 years) and B-vehicle Control drivers (Mean = 49.7 years). The age distribution of drivers did however differ with the proportion of drivers aged 18 – 25 years and 76+ years being higher among Case drivers than Control drivers ($p \leq 0.05$). While this result may reflect ECIS Control sample response bias, the increased involvement of these two age groups in hospitalisation-severity crashes is well understood.

TABLE 3.16 DEMOGRAPHIC CHARACTERISTICS OF ECIS CASE DRIVERS INVOLVED IN LANE DEPARTURE HOSPITALISATION CRASHES AND ASSOCIATED ECIS CONTROL DRIVERS

	ECIS CASE			ECIS CONTROL		
DEMOGRAPHIC CHARACTERISTIC	A – B VEHICLE† (N = 115)	A-VEHICLE† (N = 80)	B-VEHICLE† (N = 35)	A – B VEHICLE† (N = 543)	A-VEHICLE† (N = 370)	B-VEHICLE† (N = 173)
SEX						
Male	64.3% (n = 74)	57.5% (n = 46)	80.0% (n = 28)	49.7% (n = 270)	51.4% (n = 190)	46.2% (n = 80)
Female	35.7% (n = 41)	42.5% (n = 34)	20.0% (n = 7)	50.3% (n = 273)	48.6% (n = 180)	53.8% (n = 93)
AGE (YEARS)						
Mean (SD)	48.2 (20.3)	49.1 (21.3)	46.1 (17.8)	49.4 (15.8)	49.2 (15.6)	49.7 (16.2)
Median	49.0	50.0	43.0	49.0	49.5	49.0
Range	18 - 92	18 - 92	19 - 86	17 - 85	17 - 85	18 - 83
AGE CATEGORY (YEARS)						
18 - 25	20.0% (n = 23)	22.5% (n = 18)	14.3% (n = 5)	6.6%∞ (n = 36)	7.0%∞ (n = 26)	5.8% (n = 10)
26 – 39	18.3% (n = 21)	15.0% (n = 12)	25.7% (n = 9)	22.8% (n = 124)	22.2% (n = 82)	24.3% (n = 42)
40 – 59	27.8% (n = 32)	26.3% (n = 21)	31.4% (n = 11)	39.2% (n = 213)	40.0% (n = 148)	37.6% (n = 65)
60 – 75	22.6% (n = 26)	22.5% (n = 18)	22.9% (n = 8)	27.6% (n = 150)	27.6% (n = 102)	27.7% (n = 48)
76 +	11.3% (n = 13)	13.8% (n = 11)	5.7% (n = 2)	3.7% (n = 20)	3.2% (n = 12)	4.6% (n = 8)

† % by column; ∞ includes one 17-year-old driver (Control-A).

63 For comparison, the demographic profile of the overall ECIS Case driver sample was: 55.8% male, 44.2% female; mean age of drivers was 49.4 years (Median = 48.5; Range = 18 – 93 years) and the mean and median ages of male drivers and female drivers were similar. Age categories: 18 – 25 years: 18.3%; 26 – 39 years: 19.8%; 40 - 59 years: 26.7%; 60 – 75 years: 21.7%; 76 years or older: 13.5%.

3.3.5.2 Speed choice, travel speed relative to the speed limit and crash risk for ECIS Case drivers involved in Lane Departure crashes and associated Control drivers

The percent and number of Case drivers and Control drivers travelling at or below the speed limit and exceeding the speed limit are presented in Table 3.17.

Approximately three-quarters of Case drivers (73.0%) were travelling at or below the speed limit, this being somewhat fewer than Control drivers (77.5%). The proportion of ECIS Case drivers involved in Lane Departure crashes exceeding the speed limit was higher (27.0%) than for ECIS Control drivers (22.5%). The proportion of Case drivers exceeding the speed limit by 10+ km/h was higher (6.0%) than was the case for Control drivers (2.6%).

TABLE 3.17 TRAVEL SPEED OF ECIS CASE DRIVERS INVOLVED IN LANE DEPARTURE HOSPITALISATION CRASHES RELATIVE TO THE SPEED LIMIT AND ASSOCIATED ECIS CONTROL DRIVERS

TRAVEL SPEED	CASE DRIVERS (A / B VEHICLE) (N = 115)	CONTROL DRIVERS (A / B VEHICLE) (N = 543)
At or below speed limit	73.0% (n = 84)	77.5% (n = 421)
Exceed speed limit	**27.0% (n = 31)**	**22.5% (n = 122)**
By 1.0 – 4.9 km/h	13.9% (n = 16)	13.1% (n = 71)
By 5.0 – 9.9 km/h	7.0% (n = 8)	6.8% (n = 37)
By 10.0 – 14.9 km/h	1.7% (n = 2)	1.5% (n = 8)
By 15.0 + km/h	4.3% (n = 5)	1.1% (n = 6)

3.3.5.3 Association between travel speed and crash risk in Lane Departure crashes

The association between travel speed and crash risk for Lane Departure crashes was examined. These crashes include run-off-road and head-on crashes. The travel speed of 115 drivers involved in 80 crashes was compared to 543 'control drivers', equating to a ratio of 4.7 control drivers for each crash-involved driver (i.e., 1:4.7).

Unadjusted analysis

Using conditional (fixed effects) logistic regression, the association between vehicle travel speed and being involved in a Lane Departure crash where at least one vehicle driver was hospitalised was assessed. This model did not include driver age or driver sex as co-variates and is referred to as an unadjusted analysis.

Table 3.18 and Figure 3.6 present crash involvement relative risk, or RR estimates for drivers travelling above and below the speed limit in 5 km/h increments; Figure 3.7 presents the RR estimates as the percent increase or percent decrease in the risk of being involved in a hospitalisation severity crash.

The analysis demonstrated that travel speed was associated with hospitalisation-severity crash risk and this relationship was statistically significant ($p < 0.001$). The analysis estimates that for every 1 km/h travelling above the speed limit, the relative risk of being involved in a hospitalisation-severity crash increases by 5.9% (RR: 1.06, 95% CI: 1.03 – 1.08, $p < 0.001$).

Driving in excess of the speed limit was associated with a higher crash risk. For example, for low level speeding – defined as driving 3 km/h above the speed limit – the increased risk was estimated to be 19%; the 95% confidence intervals estimate that this increased risk could be as low as 10% or as high as 28% (RR: 1.19, 95% CI: 1.10 – 1.28).

Drivers travelling 5 km/h above the speed limit had a 1.33 times higher crash risk than that of drivers travelling at the speed limit; this equates to a 33.1% increase in crash risk associated with exceeding the speed limit by 5 km/h (RR: 1.33, 95% CI: 1.18–1.51). For drivers travelling 10 km/h above the speed limit, their crash risk was 1.77 times that of drivers travelling at the speed limit (+77.2%; RR: 1.77, 95% CI: 1.38 – 2.27). Driving 15 km/h above the speed limit was associated with crash risk 2.36 times that of drivers travelling at the speed limit (+135.9%; (RR: 2.36, 95% CI: 1.62 – 3.43).

The protective effect of driving below the speed limit was also evident with, for example, drivers travelling 5 km/h below the speed limit having a 24.9% lower risk of being involved in a hospitalisation severity crash (RR: 0.75, 95% CI: 0.66 – 0.85). The protective effect of travelling below the speed limit was greater with lower travel speeds.

TABLE 3.18 CRASH INVOLVEMENT ODDS RATIO AND 95% CONFIDENCE INTERVALS RELATIVE TO DRIVING AT THE SPEED LIMIT FOR LANE DEPARTURE HOSPITALISATION CRASHES, UNADJUSTED ANALYSIS

TRAVEL SPEED RELATIVE TO DRIVING AT THE SPEED LIMIT (KM/H)	OR	95% CI	
		LOWER	UPPER
-15	0.42	0.29	0.62
-10	0.56	0.44	0.72
-5	0.75	0.66	0.85
0	**1.00**	**-**	**-**
5	1.33	1.18	1.51
10	1.77	1.38	2.27
15	2.36	1.62	3.43

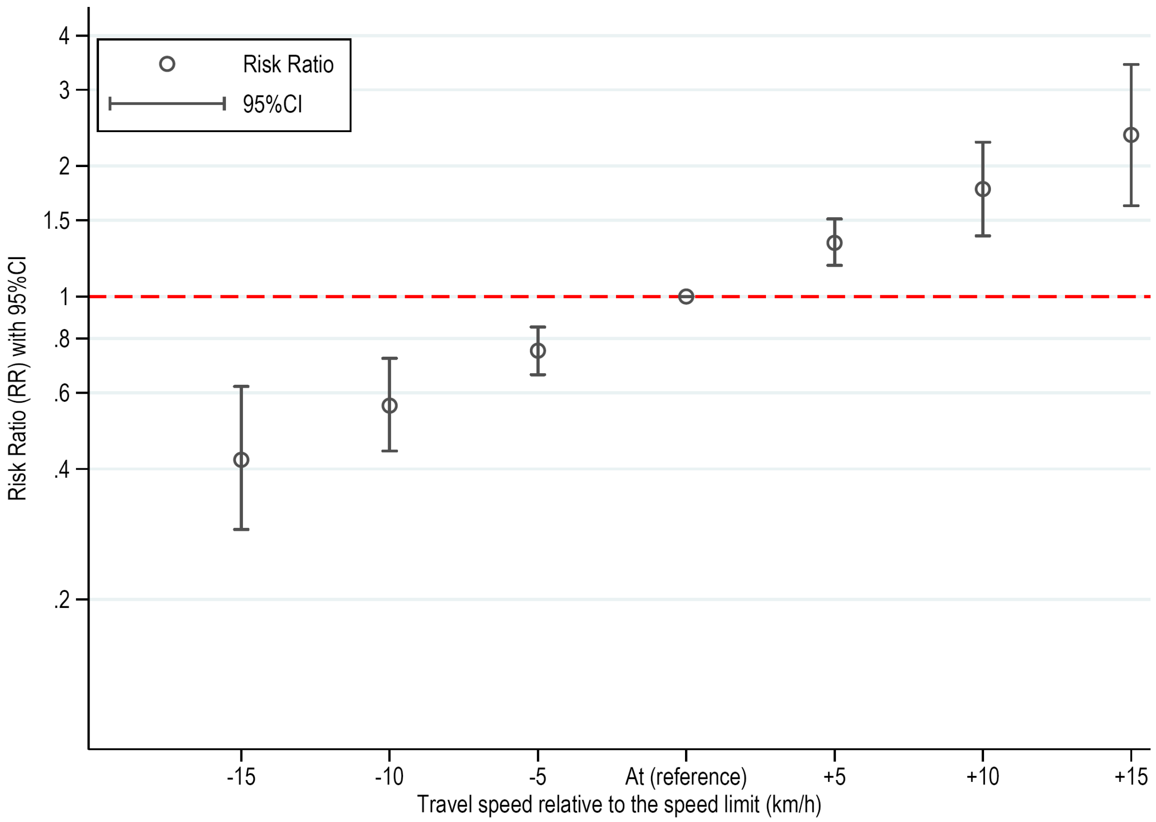

FIGURE 3.6 CRASH RISK RATIO (RR) ESTIMATES AND 95% CI VALUES FOR TRAVELLING ABOVE / BELOW THE SPEED LIMIT RELATIVE TO DRIVING AT THE SPEED LIMIT FOR LANE DEPARTURE HOSPITALISATION CRASHES (LOG SCALE), UNADJUSTED

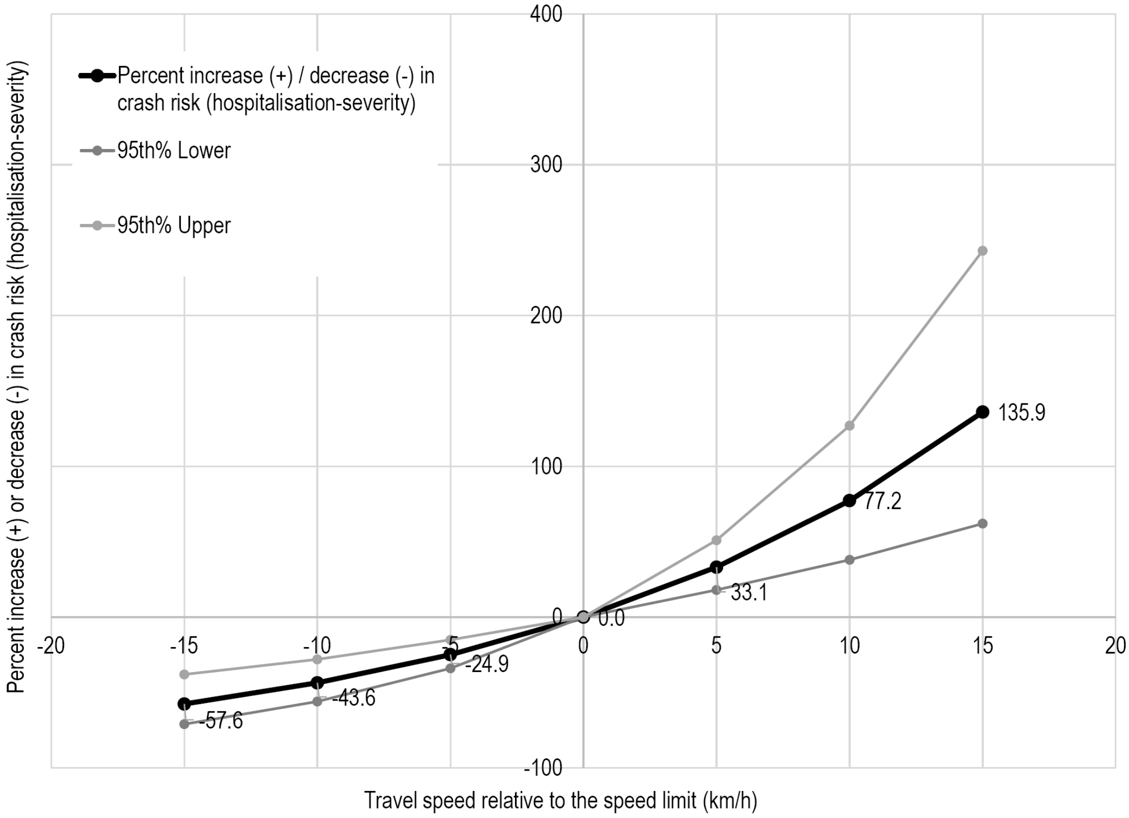

FIGURE 3.7 INCREASE (+) / DECREASE (-) IN HOSPITALISATION-SEVERITY CRASH RISK RELATIVE TO DRIVING AT THE SPEED LIMIT FOR LANE DEPARTURE CRASHES, UNADJUSTED

Adjusted analysis with the inclusion of driver age and sex

Statistical modelling was undertaken where driver age and driver sex were included. Both driver age and driver sex were strongly associated with Case status; that is, being involved in a Lane Departure crash (Table 3.19).

Table 3.20 and Figure 3.8 present crash involvement relative risk, or RR estimates for drivers travelling above and below the speed limit in 5 km/h increments; Figure 3.9 presents the RR estimates as the percent increase or percent decrease in the risk of being involved in a hospitalisation severity crash.

Accounting for driver age and driver sex and excluding crashes and drivers where alcohol and/or illicit drugs had been used, travel speed was associated with *crash risk* — defined as hospitalisation-severity crashes – and this association was statistically significant ($p < 0.001$). It can be stated that:

1. For every 1 km/h travelling above the speed limit, the relative risk of being involved in a hospitalisation-severity Lane Departure crash increases by 5.2%, adjusted for driver age and driver sex (RR: 1.05, 95% CI: 1.03 – 1.08, $p < 0.001$).

2. Driving in excess of the speed limit was associated with a higher crash risk. For low level speeding – defined as driving 3 km/h above the speed limit – the increased crash risk was estimated to be 16.3%; the 95% confidence intervals estimate that this increased risk could be as low as 8% or as high as 25% (RR: 1.16, 95% CI: 1.08 – 1.25).

   There was a 28.7% increased crash risk for drivers travelling 5 km/h above the speed limit relative to drivers travelling at the speed limit (RR: 1.29, 95% CI: 1.13 – 1.46, $p < 0.001$), while driving 10 km/h above the speed limit was associated with a 65.6% higher risk of being involved in a crash (RR: 1.66, 95% CI: 1.29 – 2.13). The relative crash risk was double that for drivers travelling 15 km/h above the speed limit relative to drivers travelling at the speed limit (RR: 2.13, 95% CI: 1.46 – 3.11).

3. The protective effect of driving below the speed limit was also evident with, for example, drivers travelling 5 km/h below the speed limit having a 22.3% lower risk of being involved in a hospitalisation severity crash (RR: 0.78, 95% CI: 0.69 – 0.88). The protective effect of travelling below the speed limit was greater with travel speeds further below the speed limit. For instance, the crash involvement risk was 39.6% lower for drivers travelling 10 km/h (RR: 0.60, 95% CI: 0.47–0.78) and 53.1% lower for drivers travelling 15 km/h below the speed limit (RR: 0.47, 95% CI: 0.32–0.68)

TABLE 3.19 CRASH INVOLVEMENT ODDS RATIO AND 95% CONFIDENCE INTERVALS FOR LANE DEPARTURE HOSPITALISATION CRASHES, ADJUSTED FOR DRIVER AGE AND SEX

PARAMETER	UNIT / CATEGORY	OR	95% CI		P-value
			LOWER	UPPER	
Travel speed	Per 1 km/h	1.05	1.03	1.08	<0.001
Driver sex					
	Female	Reference			
	Male	1.73	1.10	2.73	0.02
Driver age					
	18 – 25 years	Reference			
	26 – 39 years	0.27	0.12	0.58	0.001
	40 – 59 years	0.32	0.15	0.66	0.002
	60 – 75 years	0.31	0.14	0.68	0.003
	76+ years	1.34	0.50	3.60	0.6

TABLE 3.20 CRASH INVOLVEMENT ODDS RATIO AND 95% CONFIDENCE INTERVALS RELATIVE TO DRIVING AT THE SPEED LIMIT FOR LANE DEPARTURE HOSPITALISATION CRASHES, ADJUSTED FOR DRIVER AGE AND SEX

TRAVEL SPEED RELATIVE TO DRIVING AT THE SPEED LIMIT (KM/H)	OR	95% CI	
		LOWER	UPPER
-15	0.47	0.32	0.68
-10	0.60	0.47	0.78
-5	0.78	0.69	0.88
0	**1.00**	**-**	**-**
5	1.29	1.13	1.46
10	1.66	1.29	2.13
15	2.13	1.46	3.11

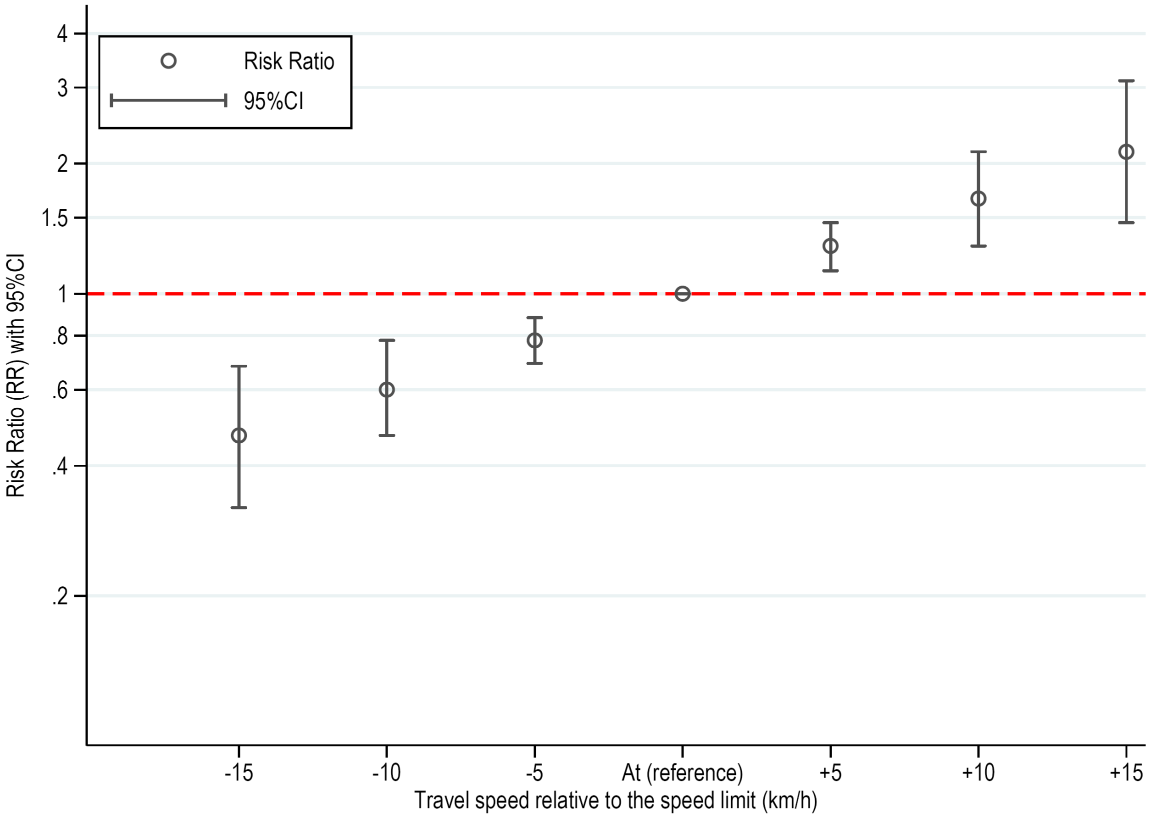

FIGURE 3.8 CRASH RISK RATIO (RR) ESTIMATES AND 95% CI VALUES FOR TRAVELLING ABOVE / BELOW THE SPEED LIMIT RELATIVE TO DRIVING AT THE SPEED LIMIT FOR LANE DEPARTURE HOSPITALISATION CRASHES (LOG SCALE), ADJUSTED FOR DRIVER AGE AND SEX

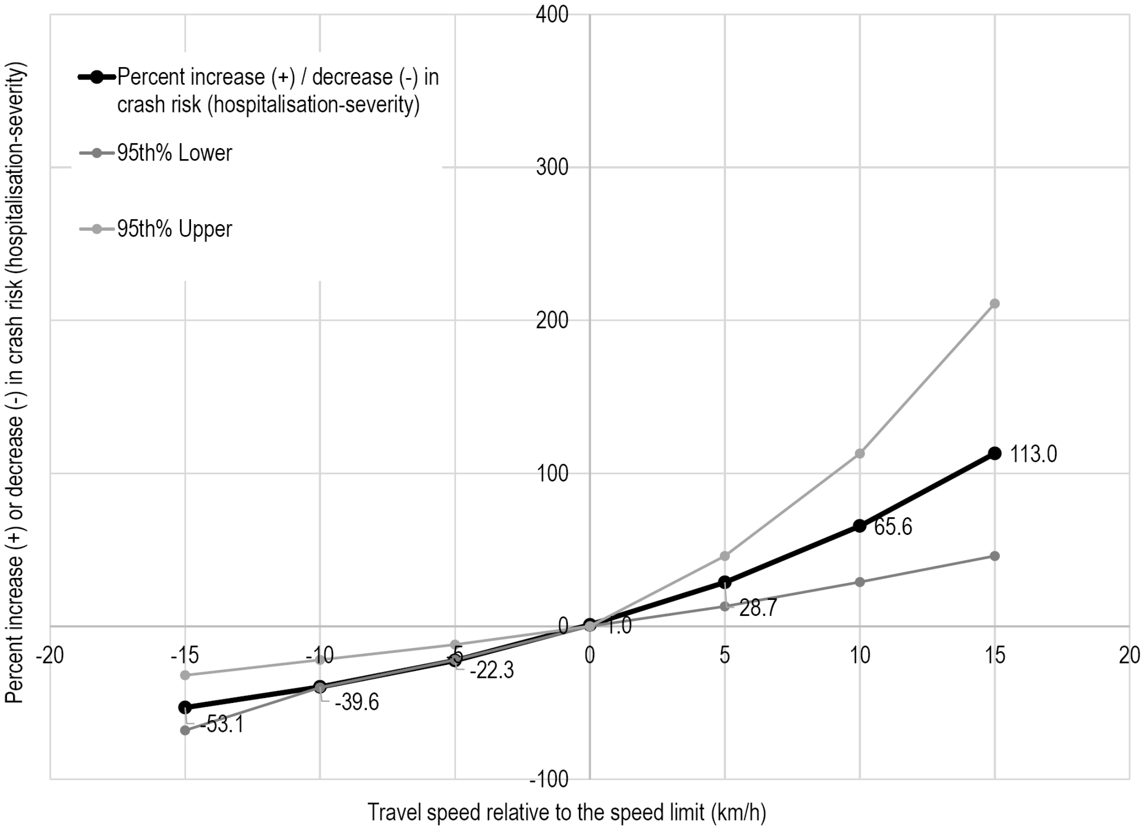

FIGURE 3.9 INCREASE (+) / DECREASE (-) IN HOSPITALISATION-SEVERITY CRASH RISK RELATIVE TO DRIVING AT THE SPEED LIMIT FOR LANE DEPARTURE HOSPITALISATION CRASHES, ADJUSTED FOR DRIVER AGE AND SEX

The analysis showed that males had 73% higher risk of being involved in a crash relative to female drivers (RR: 1.73, 95% CI: 1.10 – 2.73, p = 0.02).

Age group effects are presented in Table 3.19 with additional age-group contrasts for drivers aged 18 – 25 years and 76+ years being presented in Table 3.21. The findings demonstrate an increased crash risk for these two groups relative to other age groups, noting the crash risk of drivers aged 18 – 25 years relative to drivers aged 76+ years did not differ. This can be thought of as a classic bath-tub risk curve with no difference in the crash risk of drivers aged 26 – 39 years compared to drivers aged 40 – 59 years (p = 0.8) or drivers aged 60 – 75 years (p = 0.4) being evident. Likewise, the crash risk did not differ between drivers aged 40 – 59 years and drivers aged 60 – 75 years (p = 0.5).

TABLE 3.21 AGE GROUP CONTRASTS: CRASH INVOLVEMENT RISK RATIO AND 95% CONFIDENCE INTERVALS FOR LANE DEPARTURE HOSPITALISATION CRASHES

AGE GROUP	RR	95% CI		P-VALUE
		LOWER	UPPER	
Driver age contrasts: focus on drivers 18 – 25 years of age				
18 – 25 years of age relative to 26 – 39 years	3.75	1.72	8.18	0.001
18 – 25 years of age relative to 40 – 59 years	3.16	1.53	6.53	0.002
18 – 25 years of age relative to 60 – 75 years	3.23	1.48	7.03	0.003
18 – 25 years of age relative to 76+ years	0.75	0.28	2.01	0.5
Driver age contrasts: focus on drivers 76+ years of age				
76+ years of age relative to 18 – 25 years	1.34	0.50	3.60	0.6
76+ years of age relative to 26 – 39 years	5.02	1.94	12.95	0.001
76+ years of age relative to 40 – 59 years	4.22	1.73	10.30	0.002
76+ years of age relative to 60 – 75 years	4.31	1.70	10.94	0.002
Other driver age contrasts				
40 – 59 years relative to 26 – 39 years	1.19	0.61	2.31	0.6
60 – 75 years relative to 26 – 39 years	1.16	0.56	2.41	0.7
60 – 75 years relative to 40 – 59 years	0.98	0.53	1.80	0.9

3.3.5.4 Estimating the crash reduction benefit of eliminating speed limit non-compliance (i.e., speeding) specific to Lane Departure crashes

The PAF was calculated to estimate the percent of Lane Departure hospitalisation crashes that could be eliminated by achieving 100% compliance with the speed limit. In the unadjusted statistical model, the PAF was 9.3% while in the driver age – driver sex adjusted statistical model the PAF was 7.5%. Hence, a 7.5% reduction in hospitalisation-severity Lane Departure crashes could be achieved by ensuring 100% speed limit compliance with current speed limits, noting the assumptions stated in the *Method* (Section 2.3.4).

3.3.6 Across Path crashes: The association between travel speed and hospitalisation-severity crash risk

This section examines the association between travel speed and crash risk for Across Path crashes. A total of 66 Across Path crashes formed the basis of the analysis. This section adopts the same presentation format and analysis method used in the estimation of crash risk where all crashes were used (Section 3.3.4).

3.3.6.1 Demographic profile of ECIS Case drivers and ECIS Control drivers

The age and sex profile of the ECIS Case drivers (n = 132) involved in Across Path crashes and the associated ECIS Control drivers (n = 496) are presented in Table 3.22.

Overall, 51.5% of ECIS Case drivers were male and 48.5% were female. Similarly, 50.6% of ECIS Control Arm drivers were male and 49.4% were female (p = 0.9). The proportions of male and female A-vehicle Case drivers (Male: 34.8%; Female: 65.2%) and B-vehicle Case drivers (Male: 68.2%; Female: 31.8%) were reversed (p = 0.02). In contrast, the proportions of male and female Control A-vehicle and B-vehicle drivers were similar. The reader is referred to Section 3.1.1 for a discussion of the potential basis for this difference and the need to examine the influence of driver sex on the relationship between travel speed and crash risk, in addition to whether crash risk was seen to differ between male and female drivers.

TABLE 3.22 DEMOGRAPHIC CHARACTERISTICS OF ECIS CASE DRIVERS INVOLVED IN ACROSS PATH HOSPITALISATION CRASHES AND ASSOCIATED ECIS CONTROL DRIVERS

	ECIS CASE			ECIS CONTROL		
DEMOGRAPHIC CHARACTERISTIC	A – B VEHICLE† (N = 132)	A-VEHICLE† (N = 66)	B-VEHICLE†∞ (N = 66)	A – B VEHICLE† (N = 496)	A-VEHICLE† (N = 258)	B-VEHICLE† (N = 238)
SEX						
Male	51.5% (n = 68)	34.8% (n = 23)	68.2% (n = 45)	50.6% (n = 251)	49.6% (n = 128)	51.7% (n = 123)
Female	48.5% (n = 64)	65.2% (n = 43)	31.8% (n = 21)	49.4% (n = 245)	50.4% (n = 130)	48.3% (n = 115)
AGE (YEARS)						
Mean (SD)	49.2 (15.8)	58.9 (20.4)	43.4 (18.0)	51.2 (20.7)	44.5 (15.6)	50.1 (15.9)
Median	50.0	64.0	42.5	49.0	48.0	51.0
Range	18 - 93	19 - 89	16 - 93∞	18 - 93	18 - 93	18 - 88
AGE CATEGORY (YEARS)						
18 - 25	12.9%∞ (n = 17)	9.1% (n = 6)	16.7%∞ (n = 11)	9.1% (n = 45)	7.8% (n = 20)	10.5% (n = 25)
26 – 39	19.7% (n = 26)	12.1% (n = 8)	27.3% (n = 18)	19.0% (n = 94)	22.9% (n = 59)	14.7% (n = 35)
40 – 59	31.1% (n = 41)	24.2% (n = 16)	37.9% (n = 25)	44.0% (n = 218)	43.4% (n = 112)	44.5% (n = 106)
60 – 75	20.5% (n = 27)	28.8% (n = 19)	12.1% (n = 8)	24.6% (n = 122)	22.5% (n = 58)	26.9% (n = 64)
76 +	15.9% (n = 21)	25.8% (n = 17)	6.1% (n = 4)	3.4% (n = 17)	3.5% (n = 9)	3.4% (n = 8)

† % by column; ∞ includes one 16-year-old driver and one 17-year-old driver (Case B-vehicle).

The mean age of ECIS Case drivers (A, B) (Mean = 49.2 years)[64] was similar to the ECIS Control drivers (A, B) (Mean = 51.2 years) (p = 0.2). The mean age of A-vehicle Case drivers (Mean = 58.9 years) was older than B- vehicle Case drivers (Mean = 43.4 years), A-vehicle Control drivers (Mean= 44.5 years) and B-vehicle Control drivers (Mean = 50.1 years) ($p \leq 0.05$). The comments made with respect to the sex difference between A- and B-vehicle Case drivers (Section 3.1.1) may also be applicable to this difference in driver age.

The age distribution of drivers differed with the proportion of drivers aged 18 – 25 years and 76+ years in particular being higher among Case drivers than Control drivers ($p \leq 0.05$). This latter result may reflect ECIS Control sample response bias, however increased involvement of these two age groups in hospitalisation-severity crashes is well understood.

3.3.6.2 Speed choice, travel speed relative to the speed limit and crash risk for ECIS Case drivers involved in Across Path crashes and associated Control drivers

The percent and number of Case drivers involved in Across Path and associated Control drivers travelling at or below the speed limit and exceeding the speed limit is presented in Table 3.23.

Overall, the level of compliance with the speed limit was high with 88.6% of Case drivers and 92.7% of Control drivers travelling at or below the speed limit. The proportion of Case drivers exceeding the speed limit was somewhat higher (11.4%) than Control drivers (7.3%).

As shown in Table 3.23, the relatively small sample size and relatively low number of drivers exceeding the speed limit means that there were few drivers within each speed exceedance category.

TABLE 3.23 TRAVEL SPEED OF ECIS CASE DRIVERS INVOLVED IN ACROSS PATH HOSPITALISATION CRASHES RELATIVE TO THE SPEED LIMIT AND ASSOCIATED ECIS CONTROL DRIVERS

TRAVEL SPEED	CASE DRIVERS (A / B VEHICLE) (N = 132)	CONTROL DRIVERS (A / B VEHICLE) (N = 496)
At or below speed limit	88.6% (n = 117)	92.7% (n = 460)
Exceed speed limit	**11.4% (n = 15)**	**7.3% (n = 36)**
By 1.0 – 4.9 km/h	6.1% (n = 8)	5.4% (n = 27)
By 5.0 – 9.9 km/h	2.3% (n = 3)	1.2% (n = 6)
By 10.0 – 14.9 km/h	3.0% (n = 4)	0.2% (n = 1)
By 15.0 + km/h	0.0% (n = 0)	0.4% (n = 2)

3.3.6.3 Association between travel speed and hospitalisation-severity crash risk in Across Path crashes

The association between travel speed and crash risk for the 66 Across Path crashes was examined. The travel speed of 132 drivers was compared to 496 'control drivers', equating to a ratio of 3.8 control drivers for each crash-involved driver.

Unadjusted analysis

Using conditional (fixed effects) logistic regression, the association between vehicle travel speed and being involved in an Across Path crash where at least one vehicle driver was hospitalised was assessed. This model did not include driver age or driver sex as co-variates and is referred to as an unadjusted analysis.

Table 3.24 and Figure 3.10 present crash involvement relative risk, or RR estimates for drivers travelling above and below the speed limit in 5 km/h increments; Figure 3.11 presents the RR estimates as the percent increase or percent decrease in the risk of being involved in a hospitalisation severity crash.

64 For comparison, the demographic profile of the overall ECIS Case driver sample was: 55.8% male, 44.2% female; mean age of drivers was 49.4 years (Median = 48.5; Range = 18 – 93 years) and the mean and median age of male drivers and female drivers were similar. Age categories: 18 – 25 years: 18.3%; 26 – 39 years: 19.8%; 40 - 59 years: 26.7%; 60 – 75 years: 21.7%; 76 years or older: 13.5%.

The analysis demonstrated that travel speed was associated with hospitalisation-severity crash risk and this relationship was statistically significant (p <0.001). The analysis estimates that for every 1 km/h travelling above the speed limit, the relative risk of being involved in a hospitalisation-severity crash increases by 9.7% (RR: 1.10, 95% CI: 1.07 – 1.13).

Driving in excess of the speed limit was associated with a higher crash risk. For example, for low level speeding – defined as driving 3 km/h above the speed limit – the increased risk was estimated to be 32%; the 95% confidence intervals estimate that this increased risk could be as low as 22% or as high as 44% (RR: 1.32, 95% CI: 1.22 – 1.44). For drivers travelling 5 km/h above the speed limit the crash risk was 59.2% higher than for drivers travelling at the speed limit (RR: 1.59, 95% CI: 1.38 – 1.83), and was 153.3% higher when travelling 10 km/h above the speed limit (RR: 2.53, 95% CI: 1.92 – 3.35). Driving 15 km/h above the speed limit was associated with a 303.1% higher crash risk, which can also be expressed as having a crash risk 4.03 times higher than when travelling at the speed limit (RR: 4.03, 95% CI: 2.65 – 6.13, see Figure 3.10). The broadening of the confidence intervals towards the higher speed exceedance levels is a consequence of the small number of Case and Control drivers travelling at these speeds.

The protective effect of driving below the speed limit was also evident with, for example, drivers travelling 5 km/h below the speed limit having a 37.2% lower risk of being involved in a hospitalisation severity crash (RR: 0.63, 95% CI: 0.55 – 0.72). The protective effect of travelling below the speed limit was greater with lower travel speeds. For instance, the crash involvement risk was 60.5% lower for drivers travelling 10 km/h (RR: 0.39, 95% CI: 0.30–0.52) and 75.2% lower, or 0.25 times that of drivers travelling 15 km/h below the speed limit (RR: 0.25, 95% CI: 0.16–0.0.38).

TABLE 3.24. CRASH INVOLVEMENT ODDS RATIO AND 95% CONFIDENCE INTERVALS RELATIVE TO DRIVING AT THE SPEED LIMIT FOR ACROSS PATH HOSPITALISATION CRASHES, UNADJUSTED ANALYSIS

TRAVEL SPEED RELATIVE TO DRIVING AT THE SPEED LIMIT (KM/H)	OR	95% CI	
		LOWER	UPPER
-15	0.25	0.16	0.38
-10	0.39	0.30	0.52
-5	0.63	0.55	0.72
0	**1.00**	**-**	**-**
5	1.59	1.38	1.83
10	2.53	1.92	3.35
15	4.03	2.65	6.13

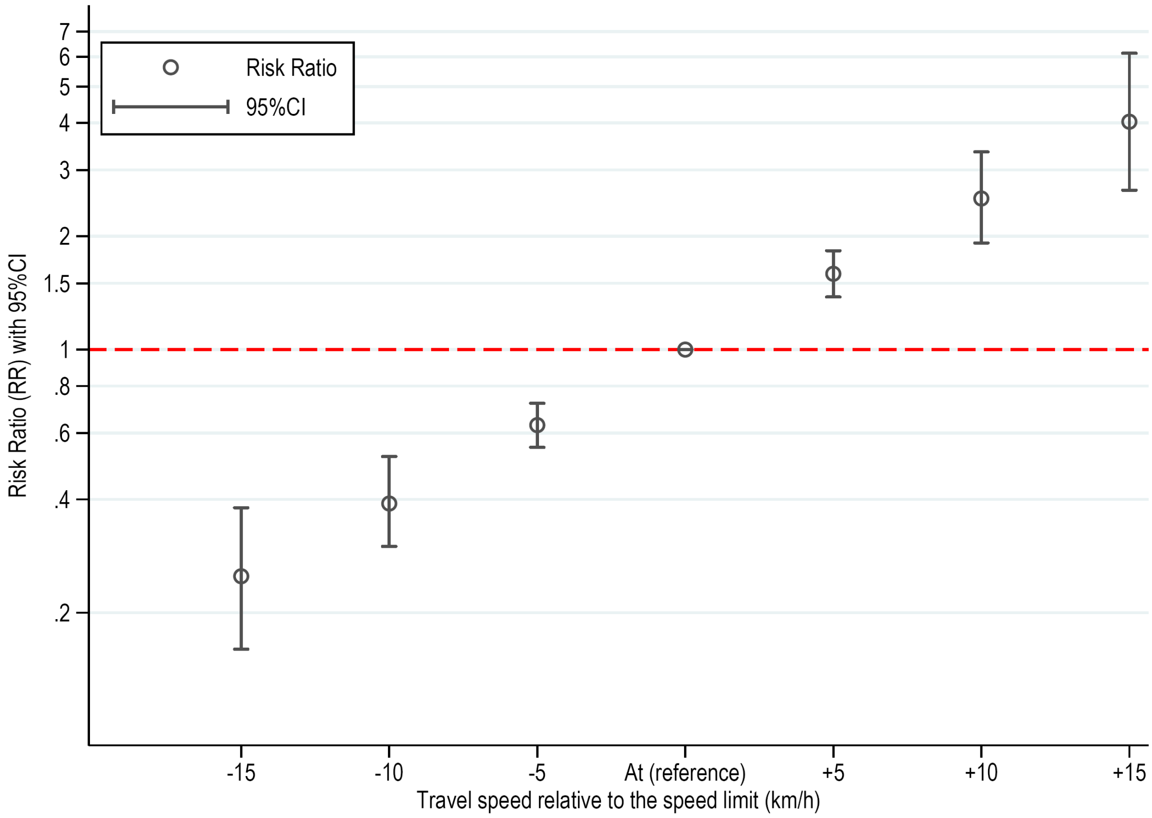

FIGURE 3.10 CRASH RISK RATIO (RR) ESTIMATES AND 95% CI VALUES FOR TRAVELLING ABOVE / BELOW THE SPEED LIMIT RELATIVE TO DRIVING AT THE SPEED LIMIT FOR ACROSS PATH HOSPITALISATION CRASHES (LOG SCALE), UNADJUSTED

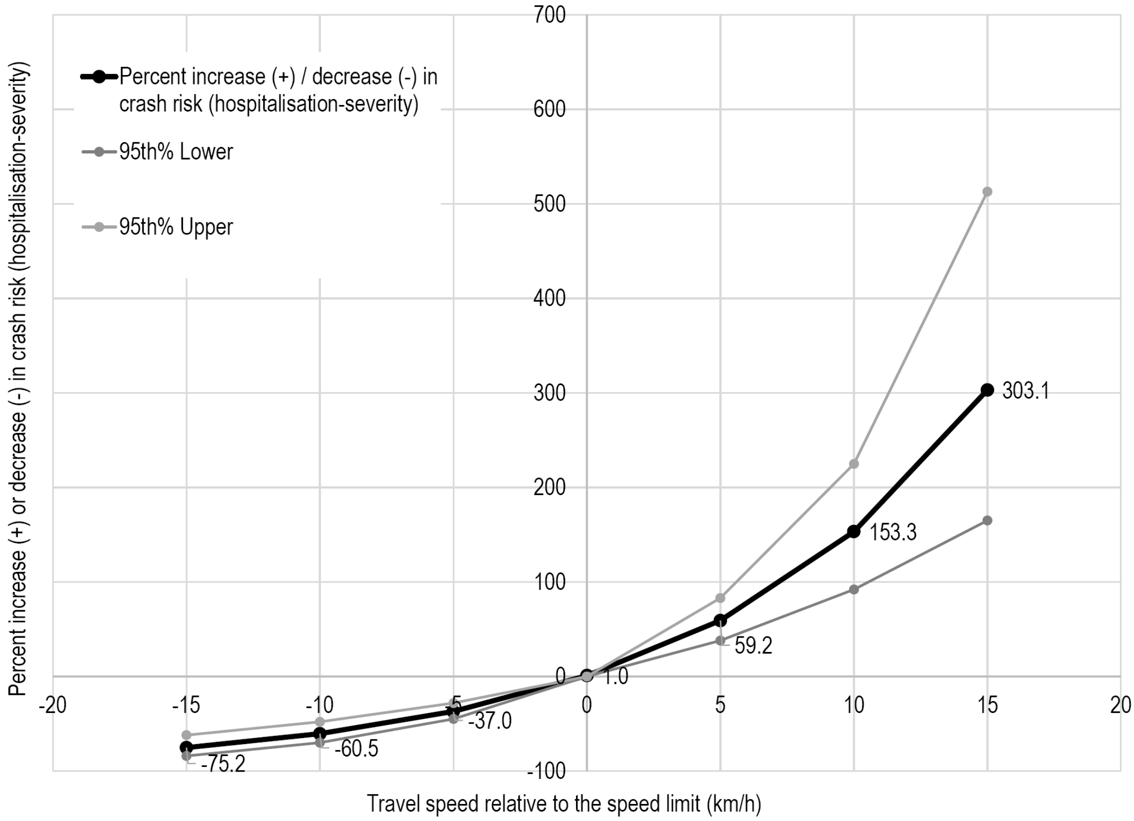

FIGURE 3.11 INCREASE (+) / DECREASE (-) IN HOSPITALISATION-SEVERITY CRASH RISK RELATIVE TO DRIVING AT THE SPEED LIMIT FOR ACROSS PATH HOSPITALISATION CRASHES, UNADJUSTED

Adjusted Model with the inclusion of driver age

Statistical modelling was undertaken where driver age and driver sex were examined. While driver age was strongly associated with being involved in a crash (i.e., being a Case), driver sex was not (p = 0.8). The crash risk ratios associated with travel speed (per 1 km/h change.

Table 3.26 and Figure 3.12 present crash involvement relative risk, or RR estimates for drivers travelling above and below the speed limit in 5 km/h increments; Figure 3.13 presents the RR estimates as the percent increase or percent decrease in the risk of being involved in a hospitalisation severity crash.

Accounting for driver age and excluding crashes and drivers where alcohol and/or illicit drugs had been used, travel speed was associated with *crash risk* — defined as hospitalisation-severity crashes – and this association was statistically significant (p < 0.001). It can be stated that:

1. For every 1 km/h travelling above the speed limit, the relative risk of being involved in a hospitalisation- severity crash increases by 10.7%, adjusted for driver age and driver sex (RR: 1.11, 95% CI: 1.07 – 1.14).
2. Driving in excess of the speed limit was associated with a higher crash risk. For example, for low level speeding – defined as driving 3 km/h above the speed limit – the increased crash risk was estimated to be 35.5%; the 95% confidence intervals estimate that this increased risk could be as low as 23% or as high as 49% (RR: 1.33, 95% CI: 1.23 – 1.49).

   Drivers travelling 5 km/h above the speed limit had a 1.66 times higher crash risk than that of drivers travelling at the speed limit; this equates to a 66.0% increased crash risk (RR: 1.66, 95% CI: 1.42–1.94). Hence, it can be stated that driving at 5 km/h above the speed limit was associated with a 66% increase in crash risk compared to driving at the speed limit.

   For drivers travelling 10 km/h above the speed limit the crash risk was 2.75 times that of drivers travelling at the speed limit (RR: 2.75, 95% CI: 2.01 – 3.77), while driving 15 km/h above the speed limit was associated with a 4.6 times higher crash risk than drivers travelling at the speed limit (RR: 4.57, 95% CI: 2.85–7.33).
3. The protective effect of driving below the speed limit was also evident with, for example, drivers travelling 5 km/h below the speed limit having a 39.7% lower risk of being involved in a hospitalisation severity crash (RR: 0.60, 95% CI: 0.51 – 0.71). The protective effect of travelling below the speed limit was greater with travel speeds further below the speed limit.

TABLE 3.25 CRASH INVOLVEMENT ODDS RATIO AND 95% CONFIDENCE INTERVALS FOR ACROSS PATH HOSPITALISATION CRASHES, ADJUSTED FOR DRIVER AGE

PARAMETER	UNIT / CATEGORY	OR	95% CI		P-value
			LOWER	UPPER	
Travel speed	Per 1 km/h	1.11	1.07	1.14	<0.001
Driver age					
	18 – 25 years	Reference			
	26 – 39 years	0.66	0.27	1.63	0.4
	40 – 59 years	0.57	0.25	1.31	0.2
	60 – 75 years	0.79	0.32	1.94	0.6
	76+ years	10.58	2.89	38.78	<0.001

Age group effects are presented in Table 3.25 with further age group contrasts for drivers aged 18 – 25 years and 76+ years provided in Table 3.27. Drivers aged 76 years and older had a significantly higher crash risk than all other age groups. There was no difference in the crash risk of all other driver age categories.

TABLE 3.26 CRASH INVOLVEMENT RISK RATIO AND 95% CONFIDENCE INTERVALS RELATIVE TO DRIVING AT THE SPEED LIMIT FOR ACROSS PATH HOSPITALISATION CRASHES, ADJUSTED FOR DRIVER AGE

TRAVEL SPEED RELATIVE TO DRIVING AT THE SPEED LIMIT (KM/H)	RR	95% CI	
		LOWER	UPPER
-15	0.22	0.14	0.35
-10	0.36	0.26	0.50
-5	0.60	0.51	0.71
0	**1.00**	**-**	**-**
5	1.66	1.42	1.94
10	2.75	2.01	3.77
15	4.57	2.85	7.33

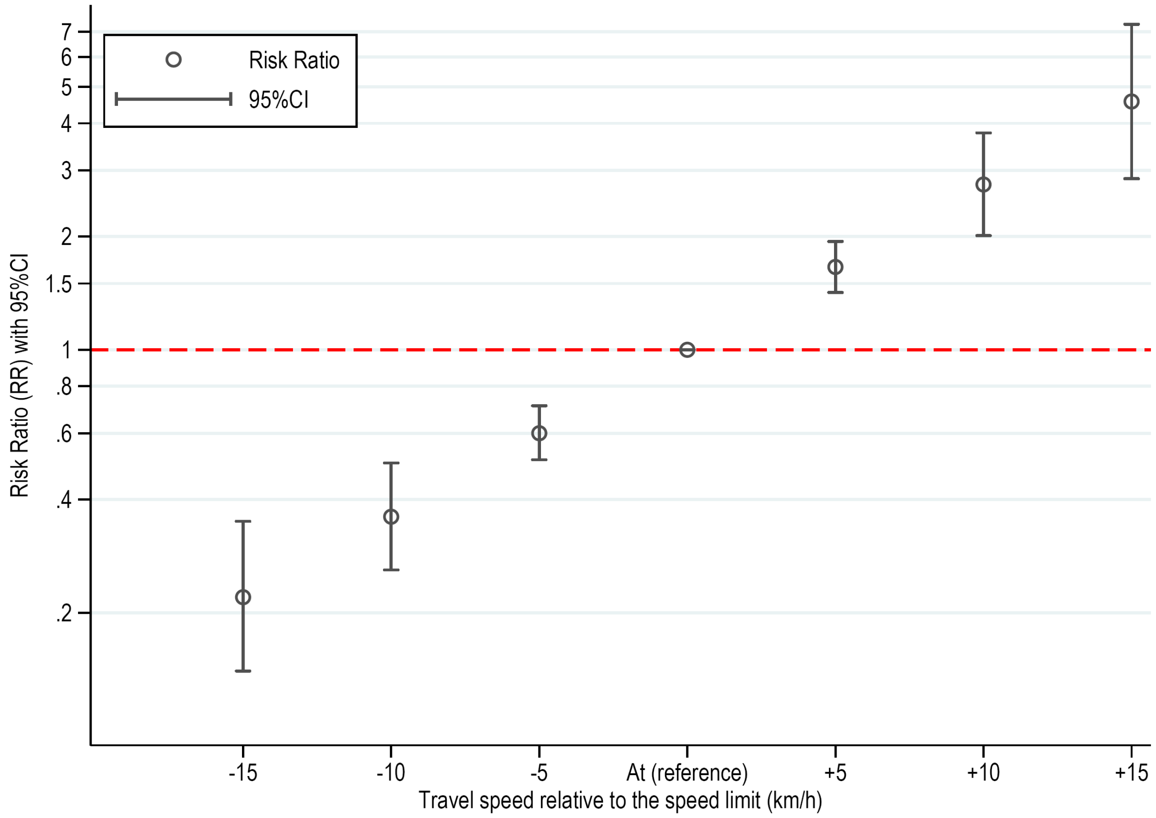

FIGURE 3.12 CRASH RISK RATIO (RR) ESTIMATES AND 95% CI VALUES FOR TRAVELLING ABOVE / BELOW THE SPEED LIMIT RELATIVE TO DRIVING AT THE SPEED LIMIT FOR ACROSS PATH HOSPITALISATION CRASHES (LOG SCALE), ADJUSTED FOR DRIVER AGE

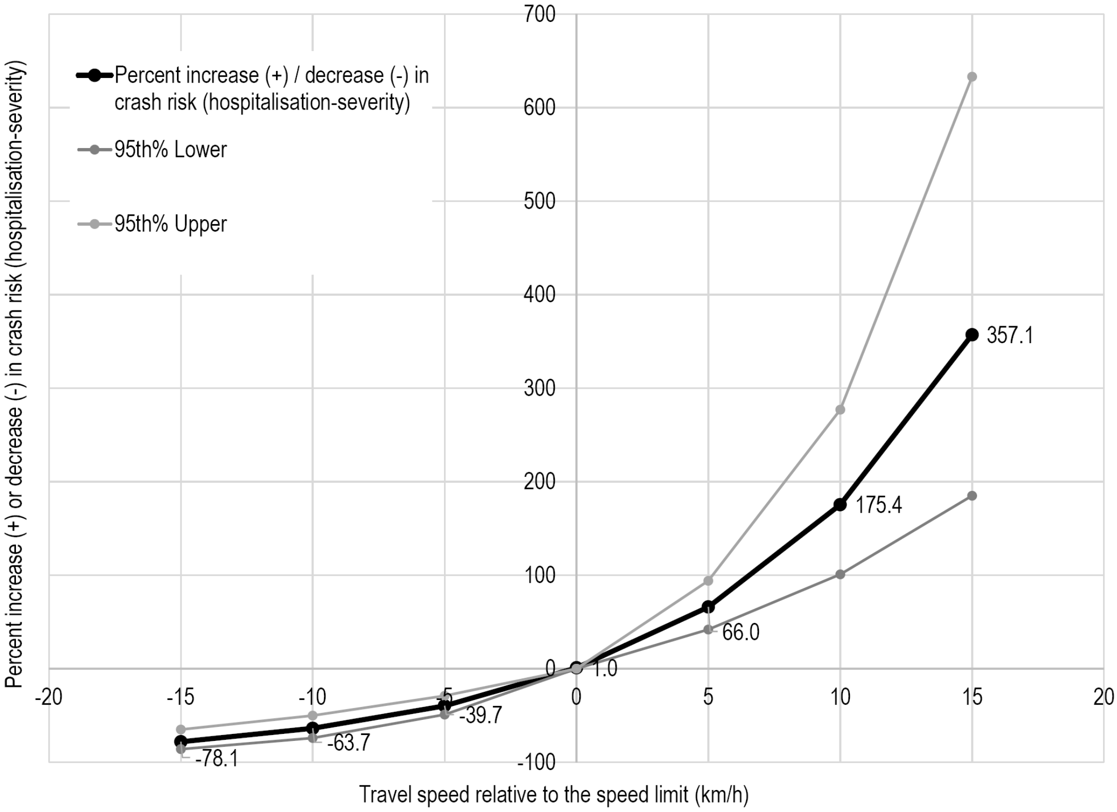

FIGURE 3.13 INCREASE (+) / DECREASE (-) IN HOSPITALISATION-SEVERITY CRASH RISK RELATIVE TO DRIVING AT THE SPEED LIMIT FOR ACROSS PATH HOSPITALISATION CRASHES, ADJUSTED FOR DRIVER AGE

TABLE 3.27 AGE GROUP CONTRASTS: CRASH INVOLVEMENT RISK RATIO AND 95% CONFIDENCE INTERVALS FOR ACROSS PATH HOSPITALISATION CRASHES

AGE GROUP	RR	95% CI		P-VALUE
		LOWER	UPPER	
Driver age contrasts: focus on drivers 18 – 25 years of age				
18 – 25 years of age relative to 26 – 39 years	1.51	0.61	3.73	0.4
18 – 25 years of age relative to 40 – 59 years	1.76	0.77	4.07	0.2
18 – 25 years of age relative to 60 – 75 years	1.27	0.51	3.12	0.6
18 – 25 years of age relative to 76+ years	0.09	0.06	0.34	< 0.001
Driver age contrasts: focus on drivers 76+ years of age				
76+ years of age relative to 18 – 25 years	10.58	2.89	38.78	<0.001
76+ years of age relative to 26 – 39 years	16.01	4.78	53.55	<0.001
76+ years of age relative to 40 – 59 years	18.66	5.95	58.52	<0.001
76+ years of age relative to 60 – 75 years	13.41	4.20	42.82	<0.001
Other driver age contrasts				
40 – 59 years relative to 26 – 39 years	0.86	0.44	1.67	0.7
60 – 75 years relative to 26 – 39 years	1.19	0.55	2.58	0.7
60 – 75 years relative to 40 – 59 years	1.39	0.72	2.70	0.3

3.3.6.4 Estimating the crash reduction benefit of eliminating speed limit non-compliance (i.e., speeding) specific to Across Path crashes

The PAF was calculated to estimate the percent of Across Path hospitalisation crashes that could be eliminated by achieving 100% compliance with the speed limit. In the unadjusted statistical model, the PAF was estimated to be 5.7% while in the driver age – driver sex adjusted statistical model the PAF was 6.9%. Hence, a 6.9% reduction in hospitalisation-severity Across Path crashes could be achieved by ensuring 100% speed limit compliance with current speed limits, noting the assumptions stated in the *Method* (Section 2.3.4).

3.4 DISCUSSION

This chapter set out to examine the relationship between travel speed and hospitalisation-severity crash risk. By comparing the travel speed of drivers involved in serious injury crashes with drivers not involved in a crash at the same location, the results demonstrate that crash risk increases as travel speed increases above the speed limit. Conversely, the protective effect of driving below the speed limit was also evident.

With respect to exceeding the speed limit, for low level speeding – defined as driving 3 km/h above the speed limit – the increased crash risk was estimated to be 25%. Driving 5 km/h above the speed limit was associated with a 44.4% increase in crash risk, relative to driving at the speed limit (Table 3.28). The increase in crash risk was higher with greater travel speeds above the speed limit.

The effect of travelling in excess of the speed limit carries with it a higher crash risk for Across Path crashes than for Lane Departure crashes (Table 3.28). For instance, travelling 3 km/h above the speed limit was associated with a 16.3% increased risk of involvement in a Lane Departure crash but a 35.5% increase in risk for involvement in an Across Path crash.

As stated, the protective effect of driving below the speed limit was also evident with, for example, drivers travelling 5 km/h below the speed limit having a 30.8% lower risk of being involved in a hospitalisation severity crash (RR: 0.69, 95% CI: 0.63 – 0.76). The protective effect of travelling below the speed limit was greater with travel speeds further below the speed limit.

Further, the analysis also highlighted the heightened crash involvement risk for male drivers, drivers 18 – 25 years of age and drivers 76 years of age and older relative to drivers in the middle age group bands.

The derivation of the PAF with respect to exceeding the speed limit and crash involvement highlights the importance of ensuring speed limit compliance. It is estimated that the elimination of speeding behaviour would deliver a 7.9% reduction in the number of hospitalisation crashes. Crucially, this is based on the speed limits as currently set, which as demonstrated in *ECIS Report 1* were wholly inadequate given the mismatch between the available infrastructure, the safety profile of the Victorian passenger vehicle fleet, and foreseeable serious injury outcomes associated with high impact speeds. Further significant reductions in serious injury trauma are possible by ensuring speed limits are set in line with best practice and 100% compliance with these revised speed limits is achieved.

TABLE 3.28 CRASH INVOLVEMENT RISK RATIOS (95% CONFIDENCE INTERVALS) AND THE POPULATION ATTRIBUTABLE FRACTION (PAF) PERCENT BY CRASH TYPE, ADJUSTED MODELS SHOWN

CRASH TYPE	Crash risk (Per 1 km/h increase)		Crash risk (Travelling 5 km/h above the speed limit, relative to driving at the speed limit)		Population Attributable Fraction (PAF) associated with exceeding speed limit‡
	RR	95% CI	RR	95% CI	PAF
All[a]	1.08†	1.06 – 1.10	1.44†	1.31 – 1.59	7.9%
Lane Departure[a]	1.05†	1.03 – 1.25	1.29†	1.13 – 1.46	7.5%
Across Path[b]	1.11†	1.07 – 1.14	1.66†	1.42 – 1.94	6.9%

† $p \leq 0.05$; ‡The PAF value is derived from statistical models using exceeding the speed limit relative to driving at or below the speed limit as a categorical variable. [a] Adjusted for driver age and driver sex; [b] Adjusted for driver age.

These findings are relevant to crashes that were sufficiently severe as to require at least one driver to be hospitalised. With the ECIS sample having a high proportion (47%) of drivers with MAIS 3+ injuries, the crash risk estimates must be interpreted and communicated with this in mind. Likewise, the findings reflect the age and sex profile of the crash-involved drivers, the characteristics and driving behaviour of the Control drivers, as well as crash location and temporal factors associated with the crashes in the ECIS sample.

The travel speed – crash risk analysis reported here relies on the travel speed estimates derived from crash reconstruction and the measurement of free travel speed of Control drivers using a laser speed camera, both of which are subject to assumptions and limitations. The reader is referred to *ECIS Report 1* and Appendix A and Appendix B of this report for an outline of the processes used to derive and record travel speed, as well as the associated limitations. While every effort was made to eliminate the potential confound associated with the use of AOD, self-report was relied upon for the Control driver sample, this being a common limitation of Case-Control studies of this kind. Further sub-group analysis was limited by the sample size.

In addition to sources of bias and measurement error noted above, the generalisability of the derived crash risk estimates is subject to the representativeness of the ECIS Case driver sample and the ECIS Control driver sample. While every effort was made in the conduct of the ECIS program to obtain a representative sample of passenger vehicles crashes at Victoria's two adult major trauma centres and a representative Control driver sample, a number of limitations do exist. For instance, in the ECIS Case Study the consent rate among young male drivers and older female drivers was lower than other age-sex groups, while the response rate for the ECIS Control survey was 33.2% (see *ECIS Report 1* for detail). Notably while only one-third of Control drivers returned the ECIS Control survey, the travel speed distribution of responders and non-responders did not differ, the proportion of drivers exceeding the speed limit was higher (+0.9%) among those returning the ECIS Control questionnaire than those who did not (see Appendix B). This provides confidence in the travel speed – crash estimates obtained and indicates that they are likely to be conservative.

Whilst these potential limitations and sources of bias exist, every effort was made to conduct a rigorous statistical analysis to extend earlier studies by statistically accounting for driver age and driver sex, excluding crashes where a driver was affected by alcohol and/or illicit drugs, as well as removing Control drivers who self-reported AOD before driving. Further, the statistical methods used take advantage of the Case-Control design such that the effects of road location and traffic density at crash location are explicitly controlled for, which is critically important when deriving estimates of crash risk across different crash locations.

Compared to Kloeden and colleagues' seminal work on the relationship between travel speed and crash risk, the crash risk estimates reported here are somewhat lower; for instance, Kloeden et al. reported a relative risk of 1.82 for travelling 5 km/h above the speed limit on Adelaide roads with a 60 km/h speed limit (cf. Table 3.28).[57] This is likely to be a consequence of differences in the types of crashes included, speed limit compliance and general road safety culture in the locations where the studies were undertaken – particularly in light of the 20 year difference in time and advances in enforcement technology, differences in the population vehicle fleet, the level of safety of crash-involved vehicles, the inclusion of crashes in multiple speed zones in the ECIS analysis, as well as other methodological (e.g., enrolment of Case and Control drivers; crash reconstruction methods) and analytical differences.

To conclude, the findings reinforce the safety benefits associated with speed limit compliance and support the earlier Case-Control studies conducted in South Australia.[65,66,67] That the sample is recent and drawn from Victoria ensures the findings are directly relevant to the Victorian road transport system.

Linking the findings of this analysis back to the *Vision Zero Model of a Safe Road Transport System* and the findings presented in *ECIS Report 1*, in particular chapter 9, these findings relate to the speed limits as currently set. As shown in *ECIS Report 1*, the high level of serious injury sustained by drivers – even those compliant with the current speed limits – highlights the gross mismatch of current speed limits with the safety performance limits of vehicles. By setting speed limits in line with the surrounding road infrastructure and in the context of vehicle safety, as well as ensuring drivers comply with these speed limits, the opportunity to reduce road trauma across the Victorian road transport system is substantial.

65 Kloeden CN, McLean AJ, Moore VM, Ponte G. Travelling speed and the risk of crash involvement. Volume 1 - Findings, CR 172. Canberra: Federal Office of Road Safety; 1997.

66 Kloeden CN, McLean AJ. Glonek G. 2002. Reanalysis of travelling speed and the risk of crash involvement in Adelaide, South Australia. CR 207. Australian Transport Safety Bureau. Canberra, Australia.

67 Kloeden CN, Ponte G, McLean AJ. 2001. Travelling speed and the risk of crash involvement on rural roads. CR 204. Australian Transport Safety Bureau. Canberra, Australia.

4 THE LINK BETWEEN TRAVEL SPEED AND VEHICLE SPEED AT IMPACT

This chapter addresses the third objective of this report, this being the relationship between the travel speed of a vehicle and the speed of the (same) vehicle at impact. This follows the preceding chapters that demonstrated the relationship between the speed limit and travel speed, and the relationship between travel speed and hospitalisation-severity crash risk.

The correlation between travel speed and the travel speed of the vehicle at impact was examined using only the ECIS Case vehicle data. The correlation analysis used the travel speed and the speed of the vehicle at impact of each driver. This was examined overall and for each speed limit zone. Analysis was conducted for drivers who braked pre-crash and those who did not brake.

4.1 TRAVEL SPEED, AVOIDANCE ACTIONS AND VEHICLE SPEED AT IMPACT

Using all of the information collected on each crash, computer-based crash reconstruction was used to estimate travel speed and vehicle speed at impact (see *ECIS Report 1* for detail; Appendix A).[68,69] Pre-crash braking and steering avoidance actions were also modelled.

This analysis used 485 crash-involved vehicles. These vehicles related to 304 crashes, including 167 Lane Departure crashes (n = 227 vehicles), 105 Across Path crashes (n = 204 vehicles) and 32 Rear Impact crashes (n = 54 vehicles, not stationary).

The mean travel speed and mean impact speed are presented in Table 4.1 for all crash types. Table 4.2, Table 4.3, and Table 4.4 present these data for vehicles involved in Lane Departure crashes, Across Path crashes and Rear Impact crashes respectively. Data were presented in this way to facilitate an understanding of speed behaviour across different speed limit zones and the correlation with vehicle speed at impact. In doing so, it is important to be cognisant of the vehicle movements in the crash, and how these differ across crash types. Of particular relevance to Across Path crashes, no distinction was made between turning and non-turning vehicles, however the lower speeds for non-braking vehicles are indicative of a high proportion of turning vehicles. As well, caution needs to be exercised in interpreting these results given the low number of vehicles in select speed limit zones.

In interpreting these findings, a distinction must be made between the speed of crash-involved vehicles at impact and the relevant impact speed with respect to injury severity. For multiple-vehicle crashes, the definition of the striking vehicle and hence the relevant impact speed can differ according to the impact configuration. The reader is referred to *ECIS Report 1* and chapter 5 of this report for further detail.

Key findings are:

- Across all crash types, 54.5% of drivers braked and 29.9% attempted to avoid the crash by steering. Steering avoidance actions were higher among drivers who braked compared to drivers who did not brake.
- Braking was higher among drivers involved in Lane Departure crashes (69.2%) than drivers involved in Across Path crashes (42.6%) and Rear Impact crashes (38.9%). For Lane Departure crashes and Across Path crashes, the proportion of drivers braking pre-crash increased at each higher speed limit.
- Steering avoidance actions were higher among drivers involved in Lane Departure crashes (43.6%) than drivers involved in Across Path crashes (19.1%) and Rear Impact crashes (12.3%).
- The mean travel speed of drivers was generally similar to the speed limit, although this did differ across crash types and between drivers who braked and drivers who did not.
- As expected, the percent reduction in travel speed to impact speed was higher among the braking vehicles (e.g., all crashes, braking: -30.9% cf. non-braking: -15.8%). There were differences in the percent speed reduction across speed zones and crash types.

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68 Pre-crash travel speed was estimated to between 4 – 7 seconds prior to the crash; the maximum plausible and physically possible speed in that interval was determined based on all evidence collected about the events of the crash. Braking modified this timeline for the relevant vehicle within each crash reconstruction.

69 To address the question of the relationship between travel speed and vehicle speed at impact, paired data for each vehicle are used. With respect to assessing the relationship between impact speed and injury severity, the relevant impact speed is that of the striking vehicle in the case of multiple-vehicle impacts; this is detailed in chapter 5.

TABLE 4.1 TRAVEL SPEED AND VEHICLE SPEED AT IMPACT BY BRAKING STATUS, BY SPEED ZONE

		DRIVER BRAKED PRE-CRASH						NO BRAKING PRE-CRASH					
SPEED LIMIT (KM/H)	NUMBER (%) OF CRASH INVOLVED DRIVERS / VEHICLES	BRAKED (%)	TRAVEL SPEED (KM/H) Mean (SD)	VEHICLE SPEED AT IMPACT (KM/H) Mean (SD)	R†	% SPEED REDUCTION	STEER IN ATTEMPT TO AVOID (%)	DID NOT BRAKE (%)	TRAVEL SPEED (KM/H) Mean (SD)	VEHICLE SPEED AT IMPACT (KM/H) Mean (SD)	R†	% SPEED REDUCTION	STEER IN ATTEMPT TO AVOID (%)
50	46 (9.5%)	26.1% (n = 12)	43.3 (10.8)	29.7 (12.4)	0.55 (ns)‡	-30.0%	8.3%	73.9% (n = 34)	33.1 (14.7)	28.5 (15.6)	0.87**	-14.4%	2.9%
60	135 (27.8%)	45.2% (n = 61)	57.4 (15.7)	38.9 (15.8)	0.64**	-32.1%	34.4%	54.8% (n = 74)	48.5 (20.1)	42.5 (20.8)	0.89**	-12.3%	10.8%
70	48 (9.9%)	50.0% (n = 24)	67.8 (14.4)	51.8 (18.3)	0.78**	-23.9%	50.0%	50.0% (n = 24)	63.5 (18.8)	57.2 (22.2)	0.81**	-10.8%	12.5%
80	103 (21.2%)	54.4% (n = 56)	76.0 (15.3)	52.1 (17.5)	0.48**	-31.2%	35.7%	45.6% (n = 47)	60.5 (28.5)	47.3 (29.3)	0.83**	-22.9%	14.9%
100	153 (31.5%)	73.2% (n = 112)	90.8 (13.1)	62.0 (19.7)	0.47**	-31.7%	59.8%	26.8% (n = 41)	75.2 (30.3)	62.3 (31.2)	0.81**	-18.4%	12.2%
All	485 (100%)	54.6% (N = 265)	[75.7] (20.7)	[52.2] (20.6)	0.67**	-30.9%	45.7%	45.4% (N = 220)	[55.3] (26.8)	[46.7] (26.6)	0.86**	-15.8%	10.9%

†R: correlation coefficient between pre-travel speed and impact speed; *: $p \leq 0.05$; ** $p < 0.001$; ‡ $p = 0.06$.
Due to low numbers, data from crashes that occurred in 40 km/h, 90 km/h and 110 km/h speed limit zones was excluded.
[ ] indicates mean across all speed zones; of value only with regard to correlation between travel speed and impact speed, overall speed reduction pre-crash.
Note: steering avoidance overall irrespective of braking: 29.9% (n = 145 of 485).

TABLE 4.2 LANE DEPARTURE CRASHES: TRAVEL SPEED AND VEHICLE SPEED AT IMPACT BY BRAKING STATUS, BY SPEED ZONE

		DRIVER BRAKED PRE-CRASH						NO BRAKING PRE-CRASH					
SPEED LIMIT (KM/H)	NUMBER (%) OF CRASH INVOLVED DRIVERS / VEHICLES	BRAKED (%)	TRAVEL SPEED (KM/H) Mean (SD)	VEHICLE SPEED AT IMPACT (KM/H) Mean (SD)	R†	% SPEED REDUCTION	STEER IN ATTEMPT TO AVOID (%)	DID NOT BRAKE (%)	TRAVEL SPEED (KM/H) Mean (SD)	VEHICLE SPEED AT IMPACT (KM/H) Mean (SD)	R†	% SPEED REDUCTION	STEER IN ATTEMPT TO AVOID (%)
50	8 (3.5%)	62.5% (n = 5)	50.6 (0.9)	36.4 (12.4)	N/A	-28.3%	20.0%	37.5% (n = 3)	51.8 (1.7)	49.9 (1.9)	N/A	-3.5%	Nil
60	52 (22.9%)	50.0% (n = 26)	63.2 (17.7)	42.0 (15.9)	0.63**	-32.8%	46.2%	50.0% (n = 26)	60.0 (14.0)	53.7 (17.8)	0.89**	-12.1%	15.4%
70	21 (9.3%)	76.2% (n = 16)	71.7 (13.8)	53.7 (20.4)	0.80**	-26.2%	56.3%	23.8% (n = 5)	73.8 (6.5)	67.9 (10.9)	N/A	-7.4%	20.0%
80	36 (15.9%)	63.9% (n = 23)	79.6 (17.8)	53.4 (19.2)	0.42*	-32.8%	47.8%	36.1% (n = 13)	81.9 (25.7)	67.9 (28.4)	0.77**	-17.0%	23.1%
100	110 (48.5%)	79.1% (n = 87)	91.1 (12.7)	60.5 (19.8)	0.39**	-33.4%	62.1%	20.9% (n = 23)	89.6 (20.3)	72.1 (27.4)	0.56*	-21.5%	17.4%
All	227 (100%)	69.2% (N = 157)	[81.5] (18.7)	[54.9] (20.4)	0.57**	-32.2%	55.9%	30.8% (N = 70)	[74.4] (22.5)	[63.2] (23.9)	0.73**	-15.4%	17.1%

†R: correlation coefficient between pre-travel speed and impact speed; *: $p \leq 0.05$; ** $p < 0.001$; N/A: not calculated due to low sample size (where N <=10).
Due to low numbers, data from crashes that occurred in 40 km/h, 90 km/h and 110 km/h speed limit zones was excluded.
[ ] indicates mean across all speed zones; of value only with regard to correlation between travel speed and impact speed, overall speed reduction pre-crash.
Note: steering avoidance overall irrespective of braking: 43.6% (n = 99 of 227).

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TABLE 4.3 ACROSS PATH CRASHES: TRAVEL SPEED AND VEHICLE SPEED AT IMPACT BY BRAKING STATUS, BY SPEED ZONE

		DRIVER BRAKED PRE-CRASH						NO BRAKING PRE-CRASH					
SPEED LIMIT (KM/H)	NUMBER (%) OF CRASH INVOLVED DRIVERS / VEHICLES	BRAKED (%)	TRAVEL SPEED (KM/H) Mean (SD)	VEHICLE SPEED AT IMPACT (KM/H) Mean (SD)	R†	% SPEED REDUCTION	STEER IN ATTEMPT TO AVOID (%)	DID NOT BRAKE (%)	TRAVEL SPEED (KM/H) Mean (SD)	VEHICLE SPEED AT IMPACT (KM/H) Mean (SD)	R†	% SPEED REDUCTION	STEER IN ATTEMPT TO AVOID (%)
50	32 (15.7%)	21.9% (n = 7)	37.9 (11.6)	24.8 (10.6)	0.45 (ns)	-31.2%	Nil	78.1% (n = 25)	29.7 (14.0)	25.9 (14.3)	0.94**	-13.5%	4.0%
60	67 (32.8%)	40.3% (n = 27)	56.4 (8.5)	38.4 (14.8)	0.63**	-32.3%	29.6%	59.7% (n = 40)	39.1 (19.8)	33.4 (18.6)	0.83*	-11.8%	7.5%
70	18 (8.8%)	33.3% (n = 6)	58.2 (15.4)	48.2 (12.5)	0.92**	-16.0%	50.0%	66.7% (n = 12)	57.4 (20.9)	49.2 (24.1)	0.73**	-26.5%	16.7%
80	55 (27.0%)	49.1% (n = 27)	72.8 (15.4)	50.0 (17.2)	0.56**	-31.1%	29.6%	50.9% (n = 28)	49.1 (26.4)	35.7 (25.8)	0.76**	-27.1%	10.7%
100	32 (15.7%)	62.5% (n = 20)	89.3 (15.5)	65.9 (18.8)	0.79**	-26.5%	50.0%	37.5% (n = 12)	45.7 (28.1)	38.3 (29.2)	0.94**	-17.1%	8.3%
All	204 (100%)	42.6% (N = 87)	[67.7] (19.8)	[48.0] (19.9)	0.79**	-29.4%	33.1%	57.4% (N = 117)	[42.0] (22.9)	[34.4] (22.1)	0.83**	-16.7%	8.5%

†R: correlation coefficient between pre-travel speed and impact speed; *: $p \leq 0.05$; ** $p < 0.001$; n.s: not statistically significant. N/A: not calculated due to low sample size (where N <=10).
Due to low numbers, data from crashes that occurred in 40 km/h, 90 km/h and 110 km/h speed limit zones was excluded.
[ ] indicates mean across all speed zones; of value only with regard to correlation between travel speed and impact speed, overall speed reduction pre-crash.
Note: steering avoidance overall irrespective of braking: 19.1% (n = 39 of 204).

TABLE 4.4 REAR IMPACT CRASHES (NON-STATIONARY VEHICLES): TRAVEL SPEED AND VEHICLE SPEED AT IMPACT BY BRAKING STATUS, BY SPEED ZONE

		DRIVER BRAKED PRE-CRASH						NO BRAKING PRE-CRASH					
SPEED LIMIT (KM/H)	NUMBER (%) OF CRASH INVOLVED DRIVERS / VEHICLES	BRAKED (%)	TRAVEL SPEED (KM/H) Mean (SD)	VEHICLE SPEED AT IMPACT (KM/H) Mean (SD)	R†	% SPEED REDUCTION	STEER IN ATTEMPT TO AVOID (%)	DID NOT BRAKE (%)	TRAVEL SPEED (KM/H) Mean (SD)	VEHICLE SPEED AT IMPACT (KM/H) Mean (SD)	R†	% SPEED REDUCTION	STEER IN ATTEMPT TO AVOID (%)
50	6 (11.1%)	Nil	-	-	-	-	-	100% (n = 6)	38.0 (13.3)	28.3 (17.8)	N/A	-23.3%	Nil
60	16 (29.6%)	50.0% (n = 8)	41.9 (15.9)	29.9 (17.7)	0.65‡	-27.9%	12.5% (n = 1)	50.0% (n = 8)	58.7 (14.8)	52.5 (20.0)	N/A	-15.7%	12.5% (n = 1)
70	9 (16.7%)	22.2% (n = 2)	65.0 (7.1)	47.5 (22.7)	N/A	-27.2%	Nil	77.8% (n = 7)	66.6 (18.7)	63.3 (21.7)	N/A	-6.9%	Nil
80	12 (22.2%)	50.0% (n = 6)	76.7 (7.3)	57.1 (12.1)	0.28 (n.s)	-15.3%	16.7% (n = 1)	50.0% (n = 6)	67.2 (13.2)	57.0 (18.8)	N/A	-16.7%	16.7% (n = 1)
100	11 (20.4%)	45.5% (n = 5)	94.2 (9.6)	72.2 (20.2)	0.72 (n.s)	-24.0%	60.0% (n = 3)	54.5% (n = 6)	79.1 (26.3)	72.6 (25.6)	N/A	-17.1%	Nil
All	54 (100%)	38.9% (N = 21)	[66.5] (24.2)	[49.4] (23.5)	0.84**	-26.6%	23.8% (n = 5)	61.1% (N = 33)	[61.8] (21.2)	[54.9] (24.3)	0.93**	-14.2%	6.1% (n = 2)

†R: correlation coefficient between pre-travel speed and impact speed; *: $p \leq 0.05$; ** $p < 0.001$; ‡ $p = 0.08$; n.s: not statistically significant; N/A: not calculated due to low sample size (where N <=10).
Due to low numbers, data from crashes that occurred in 40 km/h, 90 km/h and 110 km/h speed limit zones was excluded.
[ ] indicates mean across all speed zones; of value only with regard to overall speed reduction pre-crash.
Note: steering avoidance overall irrespective of braking: 12.3% (n = 7 of 57).

4.2 CORRELATION BETWEEN TRAVEL SPEED AND VEHICLE SPEED AT IMPACT

The data presented above serves as the basis for understanding the correlation between travel speed and vehicle speed at impact. For non-braking drivers, there was a strong[70] correlation between travel speed and vehicle speed at impact ($r = 0.86$, $p \leq 0.001$). As expected, the strength of this correlation was modified by braking ($r = 0.67$, $p \leq 0.001$; moderate correlation) (Table 4.1, Table 4.6). This pattern was consistent across the three crash types examined, although the correlation between travel speed and vehicle speed at impact was similar for braking and non-braking vehicles in Across Path crashes (see Table 4.6).

TABLE 4.6 CORRELATION BETWEEN TRAVEL SPEED AND VEHICLE SPEED AT IMPACT, BY BRAKING STATUS

	DRIVER BRAKED PRE-CRASH	NO BRAKING PRE-CRASH
CRASH TYPE	R	R
All	0.67** (n = 265)	0.86** (n = 220)
Lane Departure	0.57** (n = 157)	0.73** (n = 70)
Across Path	0.79** (n = 87)	0.83** (n = 117)
Rear Impact	0.84** (n = 21)	0.93** (n = 33)

** p < 0.001.

For vehicles that did not brake prior to the crash, the correlation between driver travel speed and vehicle speed at impact was uniformly high across speed zones (see Table 4.2 – Table 4.5). In contrast, where braking was applied the correlation coefficient values varied across speed zone and were lowest in the 80 km/h and 100 km/h speed limit zones. This likely reflects time-under-braking, which was longer in high-speed zones, particularly in Lane Departure crashes (see *ECIS Report 1*, Table 6.7).

The finding that travel speed is highly correlated with the vehicle speed at impact is important. Combined with the finding of the strong correlation between travel speed and the speed limit, it would be expected that any reduction in the speed limit would translate to lower vehicle speed at impact. The extent to which this translates to reductions in injury severity is further dependent upon a range of factors, including, for instance, impact configuration, the collision object, the safety of the vehicle and driver characteristics (e.g., frailty). The relationship between impact speed and injury severity is examined in the following chapter.

70 Schober P, Boer C, Schwarte L A. Correlation coefficients: Appropriate use and interpretation, Anesthesia & Analgesia. 2018: 126(5): 1763-1768.

5 IMPACT SPEED AND INJURY SEVERITY

5.1 INTRODUCTION

This report set out to examine the fundamental relationships that underpin the role of speed as a regulator of the safety of the road transport system (see chapter 1).[71] The conceptual underpinnings of the critical role that speed plays in shaping road safety outcomes were presented in the *Introduction*. In setting out to examine these relationships, this report has shown that:

1. Travel speed is strongly correlated with the speed limit.
2. Travel speed is associated with risk of crash involvement.
3. Travel speed is strongly correlated with impact speed.

This chapter provides the final link on the role of speed in crashes by assessing the relationship between impact speed and injury severity.

In referring to impact speed, a distinction is made between *vehicle speed at impact* and *impact speed* on the basis of which vehicle is the injury vector for a defined occupant. Impact speed uses the vehicle speed at impact but considers the struck vs. striking vehicle with respect to impact configuration. This is applicable for multiple vehicle crashes only and thus for single vehicle crashes the impact speed is the same as the vehicle speed as impact metric. The heuristic used to define impact speed is presented in the *Method* below.

Using ECIS Case data, this chapter presents an analysis of the relationship between impact speed and driver injury severity. In completing this analysis, we acknowledge the extensive body of research that has reported on crash severity and injury outcomes previously. The reader is referred to *ECIS Report 1* (chapter 1) for examination of this research literature.

The aim of the analysis is two-fold:

1. To examine the association between impact speed and injury.
2. To estimate the potential injury reduction benefit of lower impact speeds.

In this analysis, serious injury was defined as an MAIS 3+ injury. The findings of this *Report* are most relevant to crashes where one or more involved driver was admitted to hospital. Hence, the reported relationship between impact speed and injury severity, as presented in Figure 5.1, must be interpreted in this context.

5.2 METHOD

5.2.1 Injured drivers

Data from 347 ECIS Case drivers were used. Impact speed data were obtained through the crash reconstruction Type-A and Type-B process (see Appendix A). The analysis included 222 ECIS Case drivers injured in frontal impact crashes (including frontal offset crashes) and 88 ECIS Case drivers injured in side impact crashes (driver side: 66; left passenger side: 22). Side impact crashes were combined in this instance due to the low sample size of each impact type alone. Rear-struck vehicles and vehicles that experienced rollover events where the primary damage was to the roof were excluded from the analysis (n = 37).

5.2.2 Injury severity

Each verified injury was coded according to the Abbreviated Injury Scale (AIS) 2005 – Update 2008.[72] The AIS system classifies injury severity from minor (1) to maximum (6, currently untreatable). The highest severity injury is referred to as the Maximum AIS, also referred to as the MAIS score. A cut-point of AIS 3 (serious) was used to indicate 'serious' injury. This is described in detail in *ECIS Report 1*.

5.2.3 Data analysis

Logistic regression was used to establish the statistical relationship between impact speed and injury severity. The outcome variable was whether a driver sustained an MAIS 3+ injury, given involvement in a crash of the

71 Tingvall C, Lie A, Johansson R. Traffic Safety in Planning - A Multidimensional Model for the Zero Vision. In: von Holst H, Nygren Å, Andersson ÅE, editors. Transportation, Traffic Safety and Health — Man and Machine: Second International Conference. Brussels, Belgium: Springer Berlin Heidelberg; 1996, Published 2000. p. 61-9.

72 ECIS Research Nurses were trained and certified in the use of AIS 2005 – Update 2008 through the Association for the Advancement of Automotive Medicine (AAAM). In addition, the ECIS Chief Investigator (Fitzharris) has been trained in the use of AIS 1990-1998 Update and is a part of the European and Australasian Interest Group on Injury Scaling.

specified types and admission to hospital. MAIS 3+ probability values by impact speed were derived.[73,74] The presence of a statistical interaction between impact direction and impact speed was assessed and was not found; hence, for ease and to assess for the influence and/or confounding of other factors, separate statistical models for frontal impact crashes and side impact crashes were used. After the model building process,[73,74] the frontal impact statistical model was adjusted for the collision object (i.e., passenger car, 4WD/van/truck/bus; tree/pole other roadside object) and for whether the crash was a single-vehicle or multiple vehicle crash, whereas the side impact statistical model included only the impact speed.

Following the discussion above of impact speed and its relationship to *vehicle speed at impact*, impact speed was straightforward for single-vehicle crashes while for multiple vehicle impact crashes a distinction was made between the striking and struck vehicle. For a driver struck in a side impact crash, the travel speed of the 'oncoming' vehicle was more relevant; however, if the driver of interest was in the striking vehicle – and they had a frontal impact, their impact speed was used. For drivers involved in frontal crashes, the higher of the two vehicle speeds was used.

Fractional polynomials were used to assess the optimal representation of impact speed and use as a linear term in the statistical model was seen to be appropriate. Results were expressed as an odds ratio (OR) with the p-value and 95% confidence interval values also reported. Statistical significance was set at $p \leq 0.05$. Analysis was performed in SPSS v.26[75] and STATA v.16.[76]

5.3 RESULTS

5.3.1 The relationship between impact speed and injury severity

In both frontal impact and side impact crashes there was a strong relationship between impact speed and the odds of ECIS drivers sustaining an MAIS 3+ injury. This is reflected in Figure 5.1 where the probability of sustaining an MAIS 3+ injury given involvement in hospitalisation crash is shown.

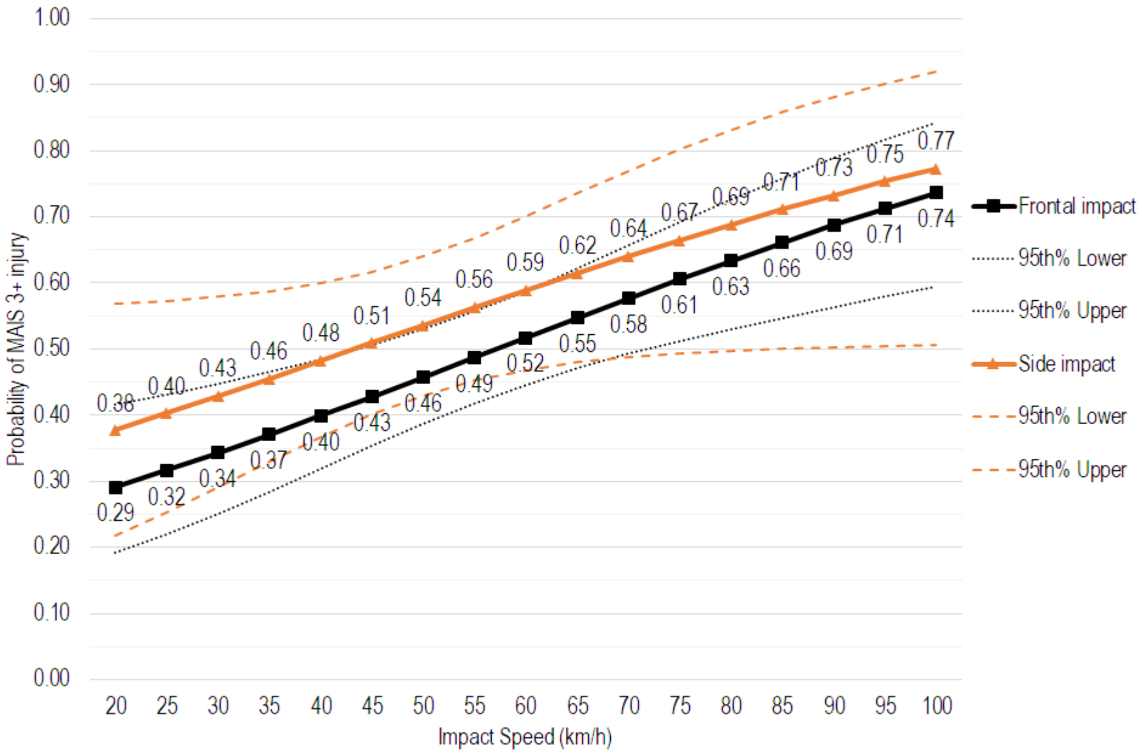

FIGURE 5.1 PROBABILITY (95% CONFIDENCE INTERVALS) OF AN ECIS DRIVER SUSTAINING AN MAIS 3+ INJURY IN FRONTAL IMPACT AND SIDE IMPACT CRASHES BY IMPACT SPEED, GIVEN ALL DRIVERS WERE HOSPITALISED

73 Vittinghoff E, Glidden DV, Shiboski SC, McCulloch CE. Regression Methods in Biostatistics: Linear, Logistic, Survival and Repeated Measures Models. New York, NY: Springer; 2005.
74 Hosmer DW, Lemeshow S. Applied Logistic Regression. 2nd ed. New York, NY: John Wiley & Sons; 1999
75 IBM. SPSS Statistics, v.25 [computer program]. IBM Corp. IBM SPSS Statistics for Windows, Version 25.0.[computer program] Armonk, NY: IBM Corp; 2017.
76 StataCorp. Stata MP Version 15 [computer program]. College Station, TX: StataCorp; 2017.

Among this sample of hospitalised drivers:

- In frontal impact crashes, the odds of a driver sustaining a MAIS 3+ injury increased by 2.4% for every 1 km/h increase in impact speed (RR: 1.02; 95% CI: 1.01 – 1.03, $p \leq 0.001$).
- In side impact crashes, the odds of a driver sustaining a MAIS 3+ injury increased by 2.2% for every 1 km/h increase in impact speed (RR: 1.02; 95% CI: 1.00 – 1.04, $p = 0.056$).

As an example, the probability of a driver sustaining an MAIS 3+ injury in a frontal crash at an impact speed of 30 km/h was found to be 34% (95% CI: 25% - 45%) compared to 43% (95% CI: 29% - 58%) if the impact was to the side of the vehicle (see Figure 5.1).

It is acknowledged that the impact speed – injury probability relationship may be modified by vehicle age and compliance with frontal impact and side impact protection vehicle safety standards in the form of Australian Design Rules (ADRs). While of interest, the intent of the analysis conducted here was to document the existence and nature of the relationship between impact speed and injury severity, defined as MAIS 3+ injuries. Further work is planned to examine the effectiveness of ADRs and related safety innovations on injury severity outcomes. The interested reader is referred to a number of publications that address this question.[77,78]

5.3.2 Key points on the relationship between impact speed and injury severity

In summary, the two key findings from this analysis are:

1. The probability of sustaining MAIS 3+ injuries increase at higher impact speeds.
2. The probability of injury to vehicle drivers is higher where the impact occurs to the side of the vehicle than to the front of the vehicle, given the same impact speed.

It can also be seen that the risks of MAIS 3+ injuries in side impact collisions and frontal impact collisions converges at higher impact speeds. That drivers involved in side impact crashes have a higher risk of MAIS 3+ injuries for the same impact speed than those injured in frontal impacts, reflects the limited protective space (i.e., crumple zone) between an impacting object and the vehicle occupant. However, at an impact speed of 60 km/h, the probability of sustaining an MAIS 3+ injury in a frontal impact is 50% and this increases rapidly with increasing impact speed. This shows that even in frontal impacts the ability of the vehicle to withstand high impact speeds and protect the occupant(s) from serious injury is severely limited.

From an analytical perspective, the frontal impact statistical probability model was adjusted for the collision object and for whether the crash was a single-vehicle or multiple vehicle crash. In contrast, the impact speed injury probability model for side impact crashes included only the impact speed. This highlights the dominance of impact speed in driving serious injury outcomes in the side impact crash configuration. For frontal impact crashes however, the nature of the striking/struck object has an important influence on the probability of injury; hence, the adjusted probability curve represents the average risk of a driver sustaining MAIS 3+ injuries, adjusted for the type of crash and object struck.

In sum, the analysis demonstrates a clear relationship between impact speed and the probability of sustaining serious injury. The injury risk is appropriately described as being only applicable to crashes that result in a driver being hospitalised.

5.4 POTENTIAL BENEFITS OF REDUCED IMPACT SPEED ON INJURY SEVERITY

The above analysis demonstrates the relationship between impact speed and the probability of sustaining MAIS 3+ injuries. It follows then that a reduction in impact speed will translate to a lower risk of injury. Using this relationship, the aggregate benefit of lower impact speeds in reducing the proportion of drivers with an MAIS 3+ injury can be derived.

Of interest are the potential benefits of lower impact speeds on injury severity outcomes. This was examined using two impact speed reduction scenarios:

1. 5 km/h impact speed reduction (Hypothetical Scenario 1).
2. 10 km/h impact speed reduction (Hypothetical Scenario 2).

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77 Fitzharris M, Stephan K. Assessment of the need for, and the likely benefits of, enhanced side impact protection in the form of a Pole Side Impact Global Technical Regulation. Monash University, 2013. http://www.infrastructure.gov.au/roads/publications/files/PSI_GTR_Report.pdf

78 Fitzharris, M., Fildes, B., Newstead, S., Logan, D. (2006). Crash-based evaluation of Australian Design Rule 69 (full frontal crash protection). Canberra: Australian Transport Safety Bureau. https://www.infrastructure.gov.au/roads/safety/publications/2006/pdf/Grant_Report200603.pdf

The outcome is the percent reduction in hospitalised drivers sustaining MAIS 3+ injuries.

5.4.1 Benefit calculation method

The benefit calculation was based on the change in the number of drivers predicted to sustain MAIS 3+ injuries. This calculation uses the relationships between impact speed and MAIS 3+ injury established by the logistic regression models for frontal impact crashes and side impact crashes presented above.

For each ECIS driver, a reduction of 5 km/h and 10 km/h was applied to the known impact speed. To establish the reduction in the percent of drivers sustaining MAIS 3+ injuries, a number of steps were taken:

1. For the baseline (original crash) scenario, the probability of sustaining an MAIS 3+ injury was determined for each driver given the estimated impact speed obtained from the crash reconstruction process. This was done using the derived logistic regression coefficients (see Figure 5.1).
2. Having reduced the impact speed by 5 km/h, the probability of each driver sustaining an MAIS 3+ injury was recalculated (Hypothetical Scenario 1).
3. Using the difference in the estimates of drivers sustaining an MAIS 3+ injury between the original crash (baseline) scenario and Hypothetical Scenario 1, the expected reduction in the percent of drivers sustaining an MAIS 3+ injury was determined.

The above steps were repeated to derive the benefits associated with a 10 km/h reduction in impact speed (i.e., Hypothetical Scenario 2). The results are presented as the percent difference in drivers sustaining MAIS 3+ injuries. These benefit calculation methods have been used to determine the injury reduction benefit of vehicle safety systems and are widely used and accepted.[79,80,81]

5.4.2 Calculated benefits: Reductions in hospitalised drivers sustaining MAIS 3+ injuries

With a 5 km/h reduction in impact speed, the analysis indicates that a 6.3% reduction in the percentage of hospitalised drivers sustaining MAIS 3+ injuries involved in frontal and side impact crashes could be achieved (Figure 5.2). This increases to a 12.2% reduction in percentage of hospitalised drivers sustaining MAIS 3+ injuries with a 10 km/h reduction in impact speed.

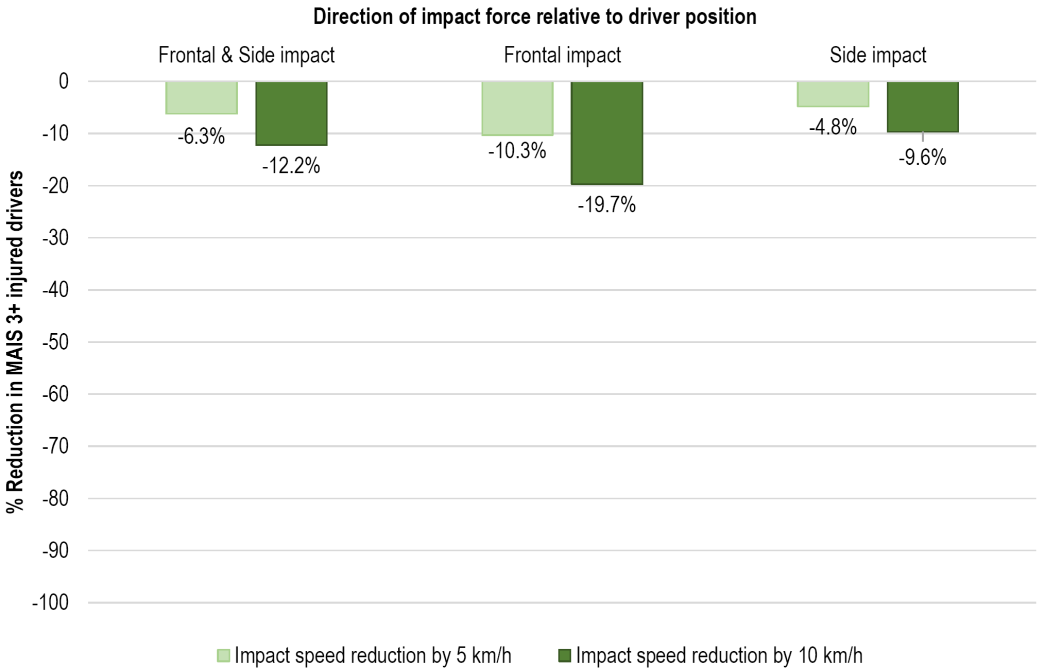


FIGURE 5.2 EXPECTED REDUCTION IN THE PERCENT OF HOSPITALISED DRIVERS WITH MAIS 3+ INJURIES GIVEN A 5 KM/H AND 10 KM/H HYPOTHETICAL REDUCTION IN IMPACT SPEED

79 Fitzharris M, Fildes B. Potential crash and injury reduction benefits of brake assist for pedestrians. Clayton: Monash University Accident Research Centre; 2007. [presentation].
80 Fitzharris M, Fildes B. Analysis of the potential crash reduction benefits of electronic brake assist, early warning systems, and the combined effect for pedestrians. Clayton: Monash University Accident Research Centre; 2007.
81 Hannawald L, Kauer F.ACEA Equal effectiveness study. Dresden: Technische Universität Dresden (TUD); 2004. https://unece.org/DAM/trans/doc/2004/wp29grsp/ps-92.pdf [presentation].

Due to the nature of the impact speed – injury severity relationship, the magnitude of the reduction in drivers sustaining MAIS 3+ injuries is higher for frontal impact crashes (-5 km/h: -10.3%; -10 km/h -19.7%) than is the case for drivers injured in side impact crashes (-5 km/h: -4.8%; -10 km/h: -9.6%). While the impact speed would be lower, it is highly likely that these remain injured, albeit at a lower severity, and most likely require hospitalisation.

The difference in the magnitude of the reduction benefit reflects the higher probability of sustaining MAIS 3+ injuries at a given impact speed, as well as differences in the impact speed distribution of side impact crashes and frontal impact crashes. Related to this is the lower level of protection a vehicle can provide in side impact crashes given the proximity of the driver to the impacting object and the perpendicular and oblique nature of the side impact compared to frontal impact crashes. The direct loading of force and the inertial forces seen in side impact crashes are markedly different than in frontal impact crashes; it is these differences that explain observed differences in injury severity outcomes, both in terms of the severity of injuries sustained for a given impact speed and the impacted body regions.[82,83]

The results are relevant to both Lane Departure crashes and Across Path crashes as impacts to the front aspect of the vehicle and the side are seen in both crash types. Based on the analysis presented earlier, given that driver speed choice is dictated to a large extent by the speed limit, and given the relationship between travel speed and impact speed presented above, reductions in impact speed could be directly achieved through reduced speed limits and road infrastructure treatments. Active vehicle systems such as Auto-Emergency Braking (AEB) can also play a role in achieving these reductions in impact speed. However, given the slow uptake of technologies such as AEB[84,85] combined with the long period of time for vehicle technology to penetrate the entire fleet,[86] the most immediate and population-centric countermeasure would be a reduction in the speed limit coupled with sustained, high-level enforcement to help ensure strong speed limit compliance over time. This would also likely be highly cost-effective given the scale of potential reductions in the number of drivers sustaining MAIS 3+ injuries on an annual basis in Victoria.

5.5 DISCUSSION

This chapter had two objectives. First, to document the association between impact speed and injury, and second, using the resultant relationship to estimate the benefit of lower impact speed on reducing the proportion of crash-involved hospitalised drivers that sustain MAIS 3+ injuries.

The finding of a strong relationship between driver MAIS 3+ injury and impact speed is unsurprising. Indeed, this relationship has long been established in vehicle safety[87] and in achieving improved road safety outcomes more generally.[88] Central to this is the concept of human injury tolerance, a concept that is at core of the *Vision Zero Model of a Safe Road Transport System* and the *Safe System* approach. Bringing these concepts together and by modelling hypothetical 5 km/h and 10 km/h reductions in impact speed, the benefit in reducing the percentage of drivers sustaining serious (MAIS 3+) injuries in crashes is clear. Noting that the analysis is agnostic as to how such impact speed reductions could be achieved, the trauma reduction benefit is significant, particularly when extrapolated across all frontal and side impact crashes.

Here, the link to driver travel speed choice and the speed limit is critical. This link, as shown in chapter 2, combined with the high correlation between travel speed and impact speed (chapter 3), plus evidence of the relationship between impact speed and serious injury in the single dataset demonstrates the critical importance of managing speed, a point made by Tingvall and colleagues[89] who described speed as the key regulator of safety in the road transport system (see chapter 1, also see *ECIS Report 1*). Collectively, these findings provide robust evidence for the role that speed plays in road trauma outcomes and how speed dictates the frequency and severity of injury that results in crashes.

As stated above, the method(s) to achieve reductions in impact speed were not specified. While road infrastructure treatments and active vehicle safety systems can play a role in achieving these reductions, the

82 Fitzharris M, Fildes B, Newstead S, Logan D. Crash-based evaluation of Australian Design Rule 69 (full frontal crash protection). Canberra: Australian Transport Safety Bureau; 2006.
83 Fitzharris M, Stephan K. Assessment of the need for, and the likely benefits of, enhanced side impact protection in the form of a Pole Side Impact Global Technical Regulation. Clayton: Monash University Accident Research Centre; 2013.
84 ANCAP. Availability of Autonomous Emergency Braking (AEB) in Australia. Canberra: ANCAP; 2020 (June).
85 Australian Government. Regulation Impact Statement: Reducing trauma from light vehicles: Autonomous emergency braking. Department of Infrastructure, Transport, Regional Development and Communications. 2020 (July).
86 Fitzharris M, Stephan K. Assessment of the need for, and the likely benefits of, enhanced side impact protection in the form of a Pole Side Impact Global Technical Regulation. Clayton: Monash University Accident Research Centre; 2013.
87 Nahum AM, Melvin JW. (Eds.). Accidental Injury: Biomechanics and Prevention. New York: Springer-Verlag; 2002.
88 Shinar D. Traffic Safety and Human Behavior: Second Edition. UK: Emerald Publishing Limited; 2017.
89 Tingvall C, Lie A, Johansson R. Traffic Safety in Planning - A Multidimensional Model for the Zero Vision. In: von Holst H, Nygren Å, Andersson ÅE, editors. Transportation, Traffic Safety and Health — Man and Machine: Second International Conference. Brussels, Belgium: Springer Berlin Heidelberg; 1996, Published 2000. p. 61-9.

analysis showed that by reducing the speed limit by 10 km/h the injury reduction benefits are significant, assuming full compliance with the revised speed limit could be achieved.

Given the very high frequency of serious injury in crashes that occurred on roads with a speed limit of 80 km/h and higher (see *ECIS Report 1*), reductions in the speed limit of 20 km/h or 30 km/h would be appropriate given the strong correlation between vehicle travel speed and impact speed, and impact speed and injury severity. Such a change would ensure most, if not all, crashes occurred at an impact speed within the safety envelope of the vehicle (see Appendix C). Reducing the speed limit by this magnitude is especially important in the context of level of safety of the present vehicle fleet and road infrastructure.

Based on the research presented here, speed limit reductions represent the primary road safety countermeasure in the absence of physical separation on high-speed roads. In the longer term, and with the goal being the elimination of serious injury, efforts to improve the safety of the fleet and roadside infrastructure, are required for the full safety benefit of speed limit reductions to be achieved.

There is a real opportunity to reduce speed limits on Victorian roads to be in line with the *Safe Roads* criteria on the basis of the relationships presented in this report that links speed limits, driver travel speed, impact speed and serious injury, as well as knowledge of limits of vehicles in protecting occupants from serious injury in high-speed crashes (refer to *ECIS Report 1*).

Based on the combination of findings and given the profound impacts of MAIS 3+ injuries on the affected person and their family, as well as the broader community impacts, there is a very strong case that further consideration be given to adopting lower speed limits where current speed limits are misaligned with the road infrastructure and broader environment. Taking this step will result prospectively in a substantial number of people saved from sustaining serious injury, with this single change translating to substantial social, environmental, and economic savings that will continue to accumulate for decades to come.

6 CASE SERIES: ILLUSTRATING THE BENEFITS OF LOWER TRAVEL SPEED ACHIEVED BY REDUCED SPEED LIMITS AND SPEED LIMIT COMPLIANCE ON CRASH OUTCOMES

This chapter examines the impact of hypothetical changes to a range of pre-crash driving scenarios on crash outcomes. The purpose is to demonstrate the practical benefits of reductions in travel speed achieved through speed limit reductions, speed limit compliance, infrastructure changes and the benefits of newer vehicles with improved safety. This work capitalises on the detailed crash reconstructions performed in the ECIS program.

6.1 BACKGROUND

The reconstruction of real-world crashes using crash simulation software is well established and is routinely used in academic research and in law enforcement. By combining multiple information sources, the crash reconstruction process represents an important part of understanding how a crash occurred, the types of forces, occupant kinematics and the consequent injuries that occupants experience.[90,91,92,93,94,95,96]

Crash reconstruction was an integral part of the ECIS program, the outcomes of which were used to model the relationship between the speed limit and travel speed (chapter 2), the relationship between travel speed and crash risk (chapter 3), the relationship between travel speed and impact speed (chapter 4), and the relationship between impact speed and injury severity (chapter 5). The outcomes from each crash reconstruction were also used to document pre-crash avoidance manoeuvres. Each crash reconstruction represented the best approximation of the events of the crash using all information obtained from the data collection process. This included a detailed re-creation of the scene of the crash.

With the ECIS program set up to identify road safety countermeasures based on how crashes and injuries occur, assessing the impact of changes in pre-crash speed, infrastructure changes and improved vehicle safety were of interest. The modification of these parameters within the computer-based crash reconstruction software environment allowed for the impact of these changes on crash outcome metrics to be examined. This represents an important innovation of the ECIS program (see *Method)*

6.2 OBJECTIVE

By implementing a series of road safety interventions within the virtual environment, the goal was to demonstrate the likely benefits of specific changes in travel speed. These represent 'hypothetical scenarios' where alternative crash outcomes can be documented. This approach represents an innovative way to communicate the likely road safety benefits of these safety measures.

6.3 METHOD

This section describes the approach adopted in the development and analysis of alternative crash scenarios based on changes to specific crash parameters. The reader is referred to *ECIS Report 1* for a full description of the project method.

The *Method* used in this chapter was developed as part of the ECIS program. A scientific peer reviewed paper was published in the journal, *Traffic Injury Prevention.*[97] The findings were presented at the *62nd Annual Conference of the Association of the Advancement of Automotive Medicine (AAAM)* held in Nashville (USA) in 2018. The paper evaluated intersection treatments for rural crossroads, including the installation of a roundabout, a reduced speed limit from 100 km/h to 80 km/h and rumble strips on approach to the

90 Fernandes FAO, Alves de Sousa RJ, Ptak M. Application of numerical methods for accident reconstruction and forensic analysis. In: Head injury simulation in road traffic accidents. Springer Briefs in Applied Sciences and Technology. Springer, Cham; 2018.

91 Franklyn M, Fildes B, Zhang L, Yang K, Sparke L. Analysis of finite element models for head injury investigation: reconstruction of four real-world impacts. Stapp Car Crash Journal. 2005;49:1-32.

92 Gabler HC, Hampton C, Roston T. Estimating crash severity: can event data recorders replace crash reconstruction? Paper presented at: Proceedings: International Technical Conference on the Enhanced Safety of Vehicles. 2003.

93 Menon RA, Ghati YS, Marigowda SB, Arbogast KB, Winston FK. Reconstruction of real-world side impact vehicle collisions using HVE–A case series of pediatric pelvic fracture. Paper presented at: HVE Forum, 2003.

94 Moser A, Steffan H. Automatic optimization of pre-impact parameters using post impact trajectories and rest positions. SAE Transactions, Section 6: Journal of Passenger Cars. 1998; 107: 897-906.

95 Richardson S, Moser A, Orton TL, Zou R. Simulation of vehicle lateral side impacts with poles to estimate crush and impact speed characteristics. SAE Technical Paper. 2015; 0148-7191.

96 Simionescu PA, Preda I. Example of a high-speed, side-impact, car crash reconstruction using a planar multibody software. Paper presented at: International Congress of Automotive and Transport Engineering; 2016.

97 Peiris, S., B. Corben, M. Nieuwesteeg, H. C. Gabler, A. Morris, D. Bowman, M. G. Lenné and M. Fitzharris (2018). Evaluation of alternative intersection treatments at rural crossroads using simulation software. Traffic Injury Prevention 19(sup2): S1-S7.

intersection. The impact of a lower speed limit plus rumble strips was also examined. This chapter presents additional alternative scenarios that used the methods developed and presented in the paper.

6.3.1 Case selection and terminology

To illustrate the effects of lower travel speed achieved by reduced speed limits and speed limit compliance, ten ECIS crashes were used. Crashes that met pre-defined crash type and speed zone features were selected, details of which are provided below. For each crash, a reconstruction had been performed. Drivers (and vehicles) were referred to as either being the A-vehicle driver or the B-vehicle driver. This distinction is based on the driver enrolled into the ECIS program. For ease, these are referred to as the A-vehicle and the B-vehicle. This naming convention is shown in Table 6.1.

TABLE 6.1 NAMING CONVENTION OF VEHICLES INVOLVED IN ECIS CRASHES

ECIS CASE NAMING CONVENTION	DETAIL
A-vehicle	**Relevant for single-vehicle crashes (SVC) and multiple-vehicle crashes (MVC)**
A-vehicle (Case vehicle)	The injured driver enrolled to the ECIS Case Study upon admission to hospital.
B-vehicle	**Relevant for multiple-vehicle crashes only (MVC)**
B-vehicle (Non-case)	For multiple-vehicle crashes, refers to the other crash-involved driver.

6.3.2 Crash reconstruction approach

The crash reconstruction process used in the ECIS program is described in detail in *ECIS Report 1* with selected information presented in Appendix A of this report. A brief summary is provided here of the crash reconstruction approach.

A number of inputs were used in the reconstruction of each crash. Inputs included: the narrative of the crash from the perspective of the driver; information obtained from Police reports and other relevant sources (i.e., Ambulance, tow truck operators, media); physical inspection of the vehicle including the measurement of vehicle damage,[98] and physical inspection of the scene. Where possible, information on pre-crash speed and braking were obtained from the Event Data Recorder (if fitted).

The computer program, *HVE*, was used to reconstruct each crash and to derive an estimate of travel speed and impact speed.[99] Within *HVE,* vehicle models were matched to the real-world crash-involved vehicle(s). When the exact vehicle was not available, a 'like' market class vehicle was used and matched on vehicle mass and other characteristics (e.g., transmission). Where ABS was fitted to the crash-involved vehicle(s), and there was evidence that a driver(s) applied the brakes, the maximum effect of ABS braking was assumed.

Three-dimensional crash scenes were created using the computer-aided design application *Rhinoceros* and imported into *HVE*. This was done to ensure correct road geometry and scale, and to replicate different surfaces that crash-involved vehicles traversed pre- and post-crash. Methods to validate each crash reconstruction included assessment of 'virtual' vehicle crush measures generated by *HVE*, the Principal Direction of Force (PDOF), and a number of other measures against the real-world damaged vehicle(s), as well as vehicle rest position(s) post-impact.

Once complete, the validated crash reconstruction represented the 'base' scenario against which road safety interventions were implemented and assessed. These interventions and the outcome metrics are discussed below.

Further information on the crash reconstruction method is available in a peer-reviewed research paper,[100] a MUARC technical report,[101] and *ECIS Report 1*. Other programs including AI-Damage and PC-Crash were also used in the ECIS program to conduct crash reconstruction and obtain key metrics, although these were not used in the development of the alternative scenarios described here.

98 SAE. Collision Deformation Classification - SAE J224 MAR80. Pennsylvania: Society of Automotive Engineers, Inc; 1980.
99 HVE V.12.10. [computer program]. Oregon: Engineering Dynamics Corporation; 2016.
100 Peiris S, Corben B, Nieuwesteeg M, Gabler HC, Morris A, Bowman D, et al. Evaluation of alternative intersection treatments at rural crossroads using simulation software. Traffic Injury Prevention. 2018;19(sup2):S1-S7.
101 Peiris S, Fitzharris M. Examination of crash reconstruction methods and speed estimation concordance with EDR captured speed data. Clayton: Monash University Accident Research Centre; 2017.

6.3.3 Road safety interventions and alternative scenarios

The primary road safety countermeasure in creating alternative crash scenarios was lower speed limits. Compliance with the revised speed limits was assumed.

Reductions in travel speed achieved via reductions in the speed limit were modelled. These included hypothetical reductions of 10 km/h, 20 km/h and 30 km/h, depending on the speed limit at the location of the crash. Compliance with the speed limit is assumed given the compliant behaviour of the driver in the original crash, otherwise compliance is 'forced'.

These scenarios were implemented in a number of different crash types and across different speed zones. These are presented in Table 6.2. The implementation of each intervention is indicated by 'X' as multiple treatments were applied to a single crash.

For the purposes of presentation, one exemplar crash of each crash type is presented within chapter 6. These were selected on the basis of their high frequency of occurrence and/or the highly injurious nature of the crash type (see *ECIS Report 1*). A further six crashes where alternative speed limit scenarios had been applied are presented in Appendix E; these are signified by grey shading in Table 6.2. These additional six cases were presented to ensure key speed limit zones were covered and unique crash sub-types were examined. Key points pertaining to each crash are documented in the relevant section below.

TABLE 6.2 MATRIX OF ROAD SAFETY INTERVENTIONS BY CRASH TYPE AND SPEED ZONE‡

CRASH TYPE (SPEED ZONE) (report section)	ROAD SAFETY INTERVENTION			
	SPEED LIMIT REDUCTION			SPEED COMPLIANCE
	By 10 km/h	By 20 km/h	By 30 km/h	
Intersection crash				
In 60 km/h speed limit (s.6.4)	X	X		X
In 80 km/h speed limit (s.F.1.1)	X	X		X
In 100 km/h speed limit (s.F.1.2)	X	X	X	X
Single-vehicle run-off-road				
In 60 km/h speed limit (s.F.2.1)	X	X		X
In 80 km/h speed limit (s.F.2.2)	X	X		X
In 100 km/h speed limit (s.6.5)	X	X	X	X
Head-on crash				
In 60 km/h speed limit (s.F.3.1)	X	X		X†
In 80 km/h speed limit (s.F.3.2)	X	X		X
In 100 km/h speed limit (s.6.5)	X	X	X	X
Rear impact crash				
In 70 km/h speed limit (s.6.6)	X	X		X†

† In the 'base' (original) crash scenario, the driver was not compliant with the speed limit prior to the crash.
‡ Clear row indicates case presented within chapter 6, while grey shading indicates that the case is presented in Appendix E.

6.3.4 Measured outcomes

HVE provides a range of crash outcome metrics for each reconstruction scenario. By comparing each metric obtained from the alternative, hypothetical scenario with the original validated crash reconstruction, the effect of each road safety measure on each crash can be assessed.

The outcome measures of interest are:

- The crash was avoided.
- The crash still occurred, but with changes in:
  - Initial velocity (travel speed), measured as km/h.
  - Impact speed, measured as km/h.

- Delta-V, measured as km/h.
- Kinetic energy, measured as Joules (J).
- Force, measured as kilonewton (kN).
- Vehicle deformation, per maximum vehicle crush measured in millimetres (mm).
- Impact point on vehicle.

6.4 RESULTS: IMPACT OF SPEED LIMIT REDUCTIONS ON EXEMPLAR INTERSECTION CRASHES

Three intersection crashes were used to demonstrate the effect of reduced speed limits (Table 6.2). These three crashes and the speed limit interventions were as follows:

1. Speed limit reductions of 10 km/h and 20 km/h where the speed limit was 60 km/h. Details are provided in Section 6.4.1.
2. Speed limit reductions of 10 km/h and 20 km/h where the speed limit was 80 km/h. The crash occurred at a signalised intersection when the A-vehicle executed a right-hand turn across the path of the B-vehicle. Details are provided in Appendix E.1.1.
3. Speed limit reductions of 10 km/h, 20 km/h and 30 km/h where the speed limit was 100 km/h. The crash involved the A-vehicle entering a high-speed carriageway to turn right; the A-vehicle was struck by an oncoming vehicle. Details are provided in Appendix E.1.2.

These three crash types are characteristic of intersection crashes seen in the ECIS program. By examining different speed limit reduction scenarios, insight into how reductions in the frequency and injury severity of these types of crashes can be gained. An exemplar crash is described here with detail regarding the other two crashes to be found in Appendix E.

6.4.1 Crash scenario: Intersection crash in a 60 km/h speed zone

The crash occurred at an unsignalized intersection approximately 10 km west of central Melbourne (capital city).

The crash occurred in the evening (approximately 20:30) in clear and dry conditions. The crash involved two drivers. The middle-aged A-vehicle driver was driving a mid-2000 model medium sized 4-star ANCAP rated car. The B-vehicle driver (early 20s age) was driving a mid-2000 model medium sized 4-star ANCAP rated car.

The crash occurred after the A-vehicle driver turned left and entered the main carriageway (i.e., arterial road) from a local street (50 km/h speed limit). The A-vehicle driver was struck by the approaching B-vehicle that was travelling on the main carriageway (60 km/h speed limit; primary state arterial road) (Figure 6.1).

The A-vehicle experienced a right-side passenger compartment impact with significant crush and intrusion into the occupant compartment. Consequently, the A-vehicle driver sustained MAIS 2 pelvic and lower extremity injuries. The B-vehicle sustained frontal damage; however, the driver was uninjured.

Based on the crash reconstruction, the travel speed estimate for the A-vehicle on entry to the intersection was 21.5 km/h, the driver did not brake, and was moving at 27.1 km/h when struck. The B-vehicle was estimated to be travelling at 60 km/h and did not brake prior to the impact. The B-vehicle (front impact) was considered to be the ‘bullet vehicle’, striking the A-vehicle (side impact) at 59.3 km/h. Hence due to the impact configurations for each vehicle, the impact speed relevant to injury severity is the same for both vehicles; this is reflected in Table 6.3 and Figure 6.3.

6.4.2 Interventions

The alternative scenarios were modelled on the main carriageway. These changes were relevant for the speed choice of the B-vehicle driver. The speed reduction measures were:

1. Reduced speed limit from 60 km/h to 50 km/h (- 10 km/h).
2. Reduced speed limit from 60 km/h to 40 km/h (- 20 km/h).

It was assumed that the B-vehicle driver would comply with the speed limit and the A-vehicle driver pre-crash behaviour would not change.

6.4.3 Crash reconstruction parameters for the intervention scenarios

The A-vehicle was matched to a passenger vehicle based on mass and geometry. The B-vehicle was matched to the actual vehicle make and model. The B-vehicle was estimated to be travelling at 60.0 km/h prior to the impact, with the speed limit also being 60 km/h. The B-vehicle driver was modelled as complying with the lower speed limits. The A-vehicle was travelling 27.1 km/h when struck. Neither driver braked prior to impact.

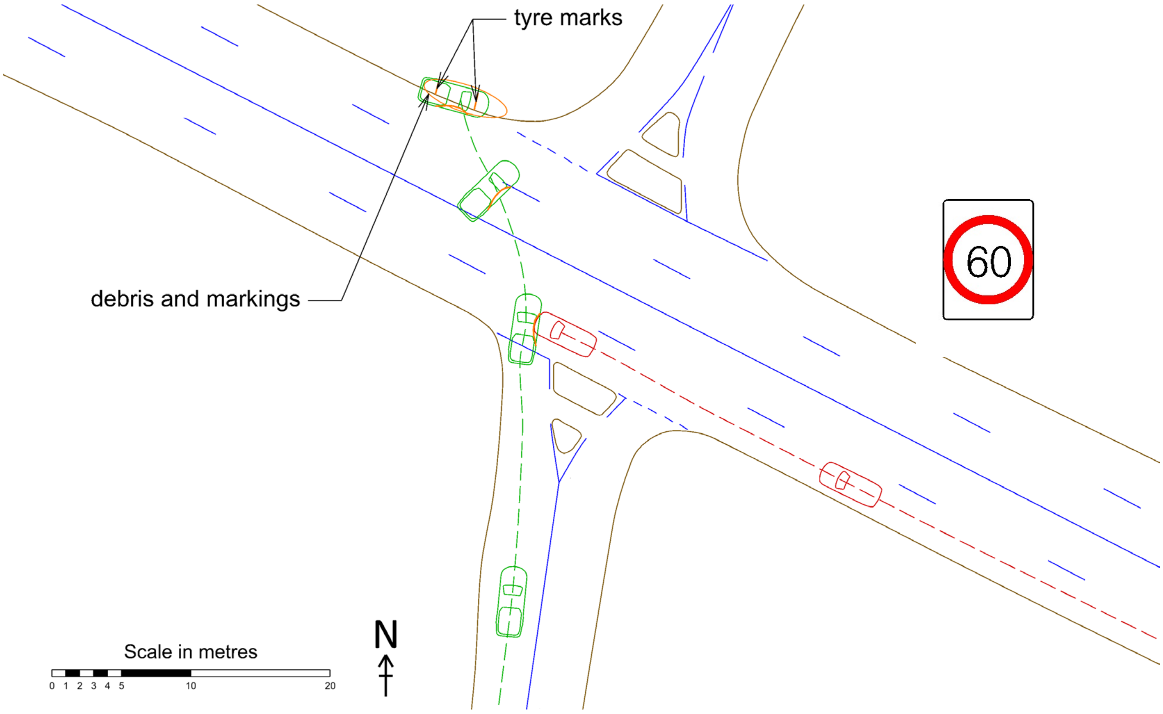


FIGURE 6.1 CRASH LOCATION AND VEHICLE MOVEMENTS

6.4.4 Crash outcomes

The A-vehicle sustained significant damage to the right (driver) door. The B-vehicle sustained moderate damage across the front centre-left of the vehicle.

In the 50 km/h and 40 km/h speed reduction intervention scenarios, the crash would still have occurred but at lower severity. This is demonstrated in a reduction in the impact velocity, the delta-V and associated force and energy metrics (Table 6.3, Figure 6.3). The change in the vehicle deformation can be seen in Figure 6.2.

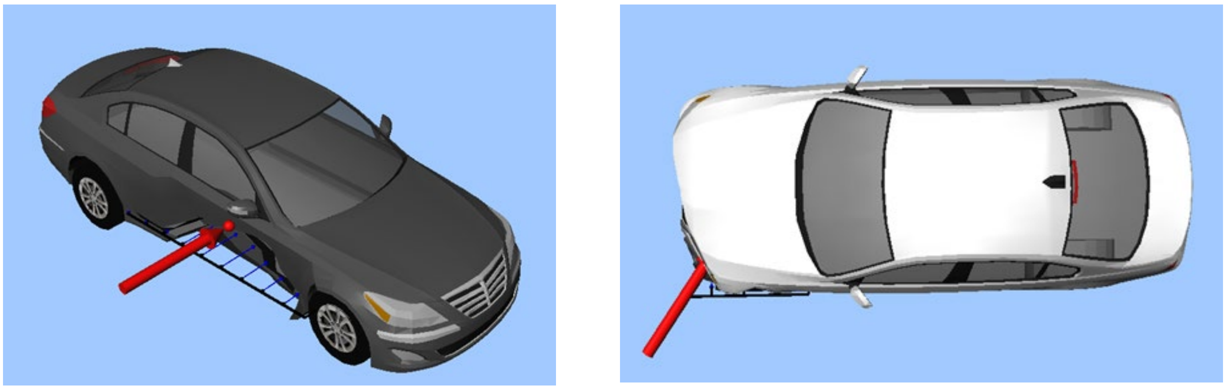
TABLE 6.3 CRASH PARAMETERS FOR THE ORIGINAL CRASH AND LOWER SPEED LIMIT SCENARIOS

VEHICLE / SCENARIO	CRASH PARAMETER							
	TRAVEL SPEED (KM/H)	IMPACT SPEED (KM/H)	DELTA-V (KM/H)	IMPACT POINT	PDOF (⁰)	PEAK FORCE (kN)	KINETIC ENERGY (J)	MAXIMUM CRUSH (MM)
A-VEHICLE								
Original crash	**27.1**	**59.3†**	**35.5**	**Right door**	**95.1**	**362.0**	**48,203**	**346**
Change in speed limit, main carriageway from 60 km/h								
To 50 km/h	27.1	50.0* [-15.7%]	24.2 [-32.5%]	Right door	94.5	312.1 [-13.8%]	48,203 [-0.0%]	293 [-15.3%]
To 40 km/h	27.1	40.0* [-32.5%]	19.6 [-32.5%]	Right door	92.7	247.8 [-31.5%]	48,197 [-0.01%]	251 [-27.4%]
B-VEHICLE								
Original crash	**60.0**	**59.3**	**38.0**	**Front left**	**-14.1**	**361.8**	**207,690**	**205**
Change in speed limit, main carriageway from 60 km/h								
To 50 km/h	50.0	50.0 [-15.7%]	27.5 [-%]	Front left	-14.7	311.8 [-13.8%]	147,575 [-28.9%]	204 [-0.5%]
To 40 km/h	40.0	40.0 [-32.5%]	22.5 [-%]	Front left	-16.4	247.5 [-31.6%]	94,312 [-54.6%]	200 [-2.4%]

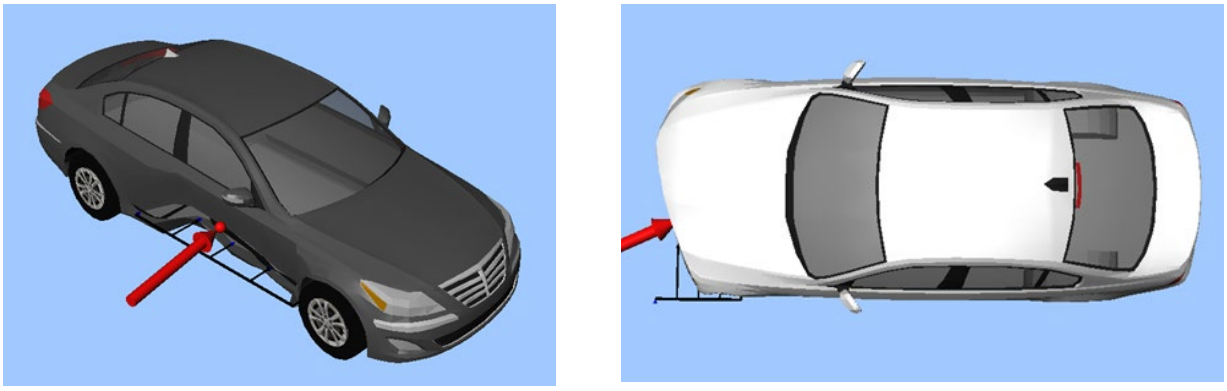
†: this is the B-vehicle speed as the 'bullet' vehicle.

A-VEHICLE	B-VEHICLE

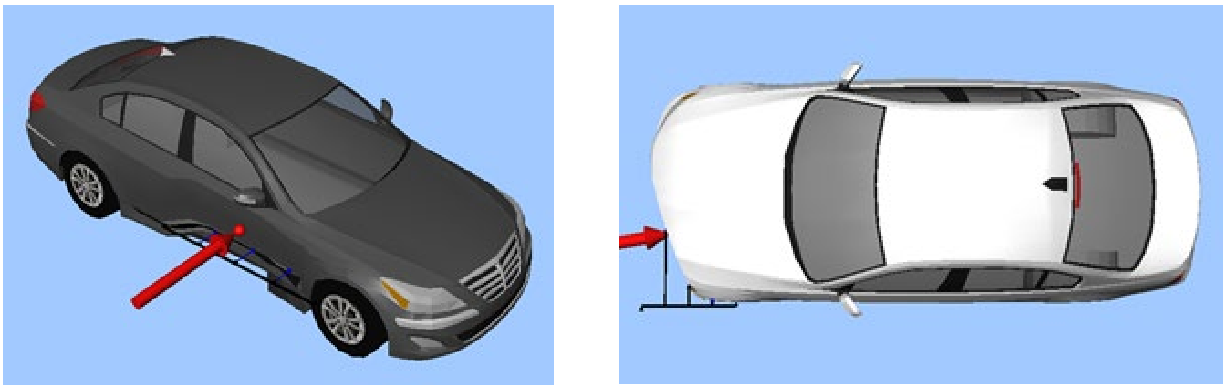
BASELINE CRASH SCENARIO (60 KM/H SPEED LIMIT, B-VEHICLE)



ALTERNATIVE SCENARIO (1): SPEED LIMIT REDUCED TO 50 KM/H



ALTERNATIVE SCENARIO (2): SPEED LIMIT REDUCED TO 40 KM/H



Note: The red arrow is the indicative PDOF.

FIGURE 6.2 CRASH RECONSTRUCTION REPRESENTATION OF IMPACT DAMAGE

FIGURE 6.3 CHANGE IN MAXIMUM CRUSH, PEAK FORCE, AND IMPACT VELOCITY BY SPEED LIMIT CHANGES FOR THE A-VEHICLE AND THE B-VEHICLE RELATIVE TO THE ACTUAL CRASH SCENARIO

6.4.5 Interpretation and summary

In both speed reduction scenarios, the crash would continue to occur. As there was no braking prior to the crash for either driver, the A-vehicle was struck on the driver side door at 50 km/h and 40 km/h, matching the speed limit. The findings assume fixed behaviour on the part of both drivers and the B-vehicle driver was modelled as complying with the lower speed limit.

The reduction in the speed limit ensures that the crash occurs at the side impact crash test speed and below that for a frontal offset crash (see Appendix C). It is expected that this will translate to a lower probability of the A-vehicle driver being seriously injured.

The reduction in maximum crush for the A-vehicle was 15.3% for the 50 km/h speed limit alternative scenario and 27.4% for the 40 km/h speed limit scenario. The delta-V and Peak Force measures were also lower.

Given the nature of the direct impact to the driver door and degree of crush, the A-vehicle driver remains at risk of an MAIS 3+ injury in the 50 km/h speed limit crash scenario; however, this risk is low (and was not seen in the actual crash scenario). In the 40 km/h impact, the crush and crash energy remain significant and hence the risk of an MAIS 2 injury remains high, particularly given the status of the vehicle as a 4-star safety rated vehicle (see Appendix C, also *ECIS Report 1* for discussion on impact speed boundary conditions).

In short, in these speed reduction scenarios the A-driver would likely continue to sustain pelvic and lower extremity injuries as was seen in the actual crash scenario. The probability of sustaining an MAIS 3+ injury is lower in the reduced speed limit scenarios; however, the A-vehicle driver does remain at risk of sustaining an MAIS 2 injury in the 40 km/h impact given the direct loading to the driver door and degree of crush. As the driver of the B-vehicle was uninjured in the original frontal crash impact, the reduction in the impact speed ensures that this remains the case noting, however, that the degree of vehicle crush is the same while the peak force was markedly less.

6.4.6 Discussion of the outcomes of speed limit reductions as applied to the three intersection crashes

The presentation of the case series provides a powerful demonstration of the highly injurious nature of intersection crashes. In many instances, these crashes involved a direct impact with the driver or passenger door at a perpendicular or oblique angle, or at best, an offset frontal impact.

In all three intersection crashes where speed limit reductions were applied (see Appendix E), reductions in travel speed translated to a reduction in impact speed. This in turn was reflected in lower peak force values, lower kinetic energy values, and lower maximum crush values. In the high speed 100 km/h intersection crash, speed limit reductions of 20 km/h or higher would lead to the crash being avoided. Using a modified set-up that ‘forced’ the crash to happen in the same way but at a lower impact speed, the improvement (i.e., reduction) in all crash metrics was significant.

While the impact speeds were reduced, the threat of serious injury to vehicle occupants remains. These examples provide useful evidence of the value of lower speed limits in improving safety. However, the three examples also demonstrate that the safety of the vehicle is a critical variable as a number of crashes occurred at speeds beyond the engineered-in safety of the vehicle. This finding points to a role for road infrastructure that ensures the physical separation of vehicles and/or the moderation of vehicle travel speeds, as well as active vehicle safety systems that intervene to manage travel speed and braking, and act to prevent a vehicle moving into the path of another vehicle where a crash is likely.

6.5 RESULTS: IMPACT OF SPEED LIMIT REDUCTIONS ON EXEMPLAR SINGLE-VEHICLE RUN-OFF-ROAD CRASHES

Three single-vehicle run-off-road crashes were used to demonstrate the effect of reduced speed limits (Table 6.2). These three crashes and the speed limit interventions were as follows:

1. Speed limit reductions of 10 km/h and 20 km/h where the speed limit was 60 km/h. The crash involved the driver losing control of the vehicle and striking a tree. Full details are provided in Appendix E.2.1.
2. Speed limit reductions of 10 km/h and 20 km/h where the speed limit was 80 km/h. The crash involved the driver of the vehicle losing control after striking a median, striking a tree and then rolling. Details are provided in Appendix E.2.2.
3. Speed limit reductions of 10 km/h, 20 km/h and 30 km/h where the speed limit was 100 km/h. The crash involved the driver losing control of the vehicle and striking a tree. Details are provided in Section 6.5.1 (below).

The primary difference between these three crashes was the speed limit of the road where they occurred. The application of speed limit reductions provides insight into the potential benefits that could be achieved. This is particularly important given the high injury severity of single-vehicle run-off-road crashes (see *ECIS Report 1*). As with the presentation of alternative intersection crash scenarios, an exemplar crash is described here with detail regarding the other two crashes to be found in Appendix E.

6.5.1 Crash scenario: Single-vehicle run-off-road crash in a 100 km/h speed zone

The crash occurred on a rural C-class undivided road approximately 230 km east of central Melbourne in rural farmland. The speed limit was 100 km/h.

The crash occurred in the morning in clear conditions on a wet road. There was pooling of water and bleeding of the bitumen on inspection. An advisory sign of 85 km/h, applicable to a curve, was present.

The young female driver was the sole occupant and was driving a late model small 5-star ANCAP rated car.

The driver was travelling at an estimated 98 km/h with the cruise control active. The vehicle went wide on a right-hand bend, departed the road to the left and impacted a tree. The driver steered to return the vehicle to the road, however with braking the vehicle began to skid across to the right side of the road. With these steering and braking inputs, the vehicle commenced to yaw anti-clockwise and skidded across the road with the right side of the vehicle leading into the tree (see point of rest, Figure 6.4). The tree was 66 cm in diameter and was 8.6 metres off the carriageway to the right. There was a row of trees beside the road with farmland on the other side. The road was delineated with left edge, right edge and centre-line markings.

The impact was on the right (driver) side located slightly behind the B-pillar. The driver sustained multiple face, chest and pelvis MAIS 2 injuries and extensive bruising. Dual frontal, side curtain and side thorax airbags were deployed during the impact. The vehicle was fitted with ABS, Brake Assist and ESC. The seat belt was used.

The travel speed was estimated to be 98.9 kmh. The impact speed with the tree was 22.9 km/h, having lost speed as it entered into a yaw.

6.5.2 Interventions

Three speed limit reductions were modelled with driver compliance assumed.

1. Reduced speed limit from 100 km/h to 90 km/h (- 10 km/h).
2. Reduced speed limit from 100 km/h to 80 km/h (- 20 km/h).
3. Reduced speed limit from 100 km/h to 70 km/h (- 30 km/h).

In the alternative scenario models, the vehicle starts in the same position. The same inputs were used.

6.5.3 Crash reconstruction parameters for the intervention scenarios

The A-vehicle was matched by type and mass. The roadway friction coefficient used was 0.55 given the wet road and the surface condition of the bitumen. The left side shoulder friction coefficient used was 0.50 and the right-side shoulder friction coefficient was 0.60. The complete road environment including trees was created.

The pre-crash peak travel speed was 98.9 km/h and the velocity at the first lane departure was 98.2 km/h.

FIGURE 6.4 CRASH LOCATION AND VEHICLE MOVEMENTS

6.5.4 Crash outcomes

In the original crash, the damage was localised to the driver door; the maximum crush was 34.5 cm. The impact velocity was 22.9 km/h.

Where the speed limit was reduced by 10 km/h to 90 km/h and the pre-crash behaviour of the vehicle was kept the same as per the original crash, the right-side impact with the tree occurs but at a higher severity (Figure 6.5, Figure 6.6, Table 6.4). The impact point is also more localised and in line with the driver right side. This is an adverse outcome. This occurs due to the overall energy of the crash being high, driven by the high initial velocity. The vehicle trajectory is altered only slightly and the rotation is also different, hence the angle of impact being less favourable to the driver.

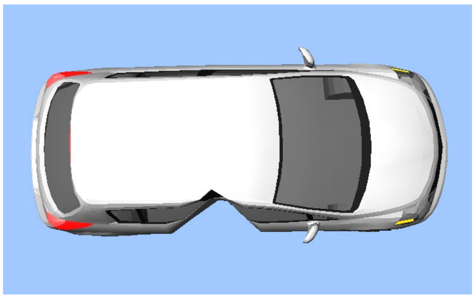
Where the speed limit was reduced to 80 km/h (and 70 km/h), the impact with the tree was avoided. In the 80 km/h speed limit scenario, the vehicle skids to a stop with the driver's side leading onto the right-side shoulder. The vehicle is undamaged.

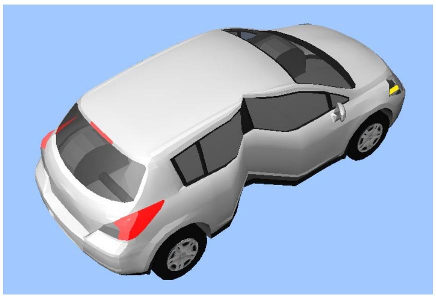
In the 70 km/h speed limit scenario, after the initial departure off to the left and crossing to the right side of the road, the driver is able to regain control of the vehicle. No crash occurs and the vehicle is undamaged.

TABLE 6.4 CRASH PARAMETERS FOR THE ORIGINAL CRASH AND LOWER SPEED LIMIT SCENARIOS

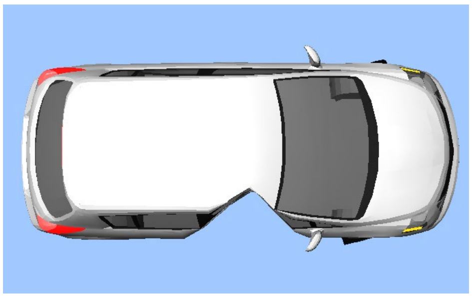
VEHICLE / SCENARIO	CRASH PARAMETER							
	TRAVEL SPEED (KM/H)	IMPACT SPEED (KM/H)	DELTA-V (KM/H)	IMPACT POINT	PDOF (^{0})	PEAK FORCE (KN)	KINETIC ENERGY (J)	MAXIMUM CRUSH (MM)
A-VEHICLE								
Original crash	**98.9**	**22.9**	**24.9**	**Right door**	**93.5**	**163.3**	**29,644**	**345**
Change in speed limit, main carriageway from 100 km/h								
To 90 km/h	91.0	29.6	33.5	Right door	92.2	239.6	47,963	430
To 80 km/h	80.9	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided
To 70 km/h	71.1	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided

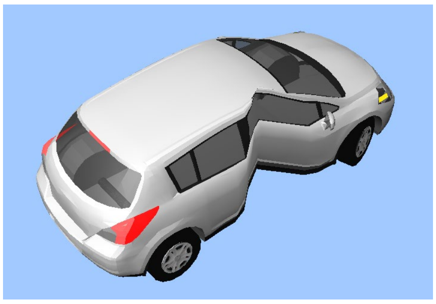
BASELINE CRASH SCENARIO (100 KM/H SPEED LIMIT)



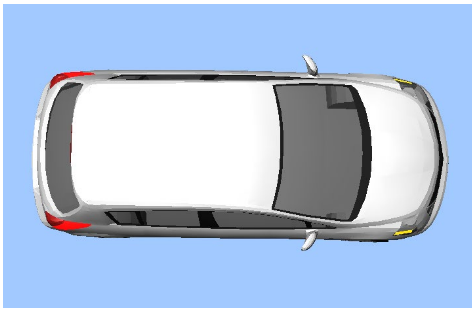


ALTERNATIVE SCENARIO (1): SPEED LIMIT OF 90 KM/H





ALTERNATIVE SCENARIO (2): SPEED LIMIT OF 80 KM/H (ALSO APPLICABLE FOR 70 KM/H SPEED LIMIT)



NO IMPACT

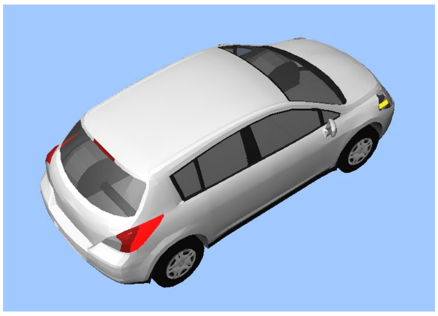


FIGURE 6.5 CRASH RECONSTRUCTION REPRESENTATION OF IMPACT DAMAGE

6.5.5 Interpretation and summary

This crash is an exemplar run-off-road crash. The crash occurred on a C-class road with a speed limit of 100 km/h. Both sides of the road were lined with trees and centre and edge line delineation provided the only safety feature. With the high-speed loss of control, the vehicle entered a yaw and travelled a considerable distance on the wrong side of the road before impacting with a tree 8.6 metres from the edge of the road. This case demonstrates the importance of physical separation, both in terms of the centreline and the side of the road itself. The driver sustained multiple MAIS 2 injuries across three body regions. The impact velocity was 22.9 km/h. The vehicle was rated as having a 5-star safety rating by ANCAP. The crash highlights the injurious nature of pole/tree side impact crashes.

The reduction in the speed limit to 90 km/h led to a higher impact speed. This adverse outcome was further exacerbated by the impact being slightly further forward of the B-pillar on the driver side which is a less stiff part of the vehicle. When the 80 km/h and 70 km/h speed limits were implemented, the collision with the tree (and others) was avoided, however, in the 80 km/h speed limit scenario the vehicle did partially leave the roadway on the right side of the road, again highlighting the high level of energy in this crash scenario. In both instances, the vehicle was on the wrong side of the road.

To conclude, the speed limit reduction to 90 km/h was insufficient to remove the energy of the crash such that the vehicle would come to a halt prior to striking the tree, as was seen when the speed limit was reduced to 80 km/h. The further reduction to 70 km/h meant that it was possible for the driver to regain control of the vehicle.

This represents an important example of the benefit of speed limit reductions given the frequency of high-speed rural road lane departure crashes in the ECIS sample (see *ECIS Report 1*). The crash can also be taken to be a model example of the performance of a 5-star vehicle in that the driver did not sustain MAIS 3+ injuries; however, with multiple MAIS 2 injuries across three body regions, this driver will require extensive medical support and rehabilitation and will likely experience significant negative on-going health impacts for a considerable period of time.

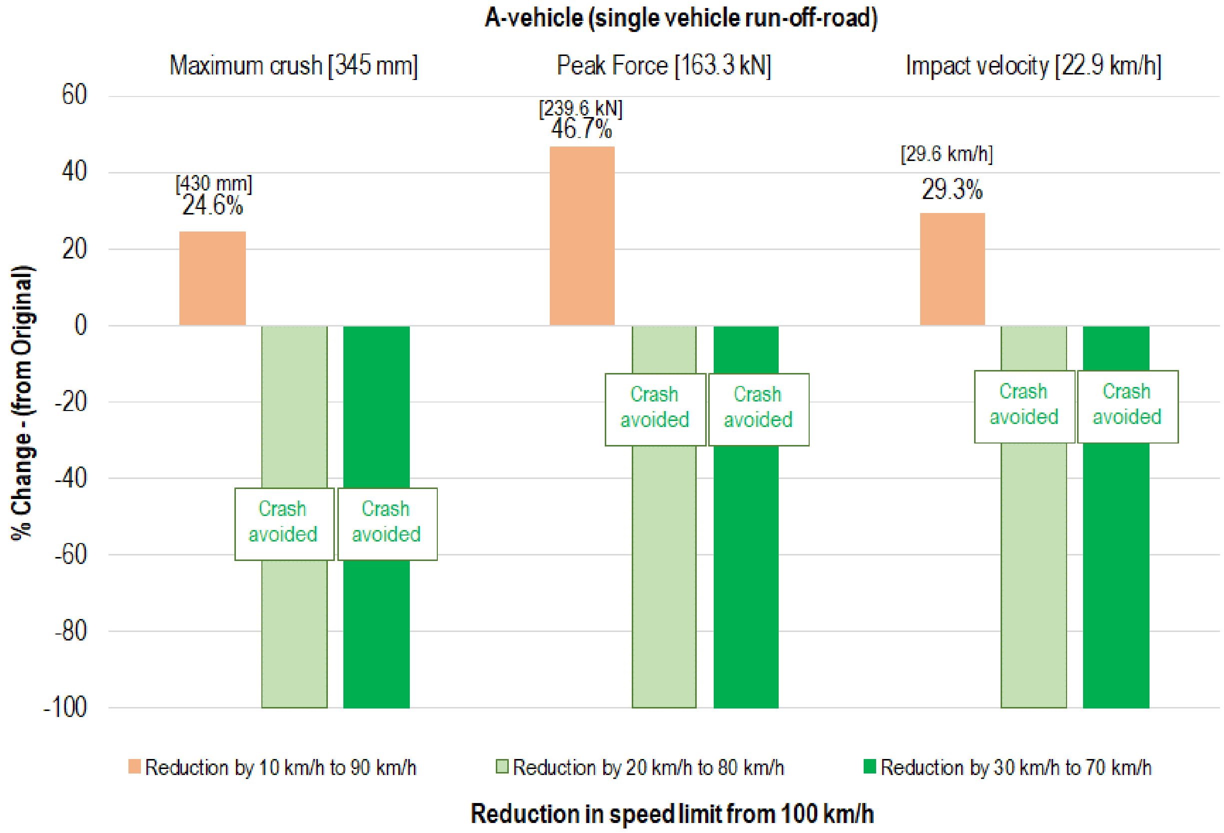


FIGURE 6.6 CHANGE IN MAXIMUM CRUSH, PEAK FORCE, AND IMPACT VELOCITY BY SPEED LIMIT CHANGES FOR THE A-VEHICLE RELATIVE TO ACTUAL CRASH SCENARIO

6.5.6 Discussion of the outcomes of speed limit reductions as applied to the three single-vehicle run-off-road crashes

The application of speed limit reductions had a significant influence on the dynamics and outcomes of all three single-vehicle crashes examined (see Appendix E). In a number of instances, an adverse outcome results by chance due to a changed and less forgiving impact point on the vehicle. In most cases, reduction of the speed limit resulted in a reduction in the impact speed–and a reduction in crash metrics–or elimination of the crash altogether.

The findings highlight the complexity of single-vehicle crashes and in particular, how a vehicle engages with roadside objects once vehicle stability is lost. Common to all crashes was the highly injurious outcomes for involved drivers and occupants, a fact driven by impact speeds that are well beyond the ability of the vehicle to provide adequate protection. This risk is especially acute where the vehicle damage is to the driver (and passenger) side of the vehicle.

Given the range of contributing factors associated with single-vehicle crashes, vehicle technology that addresses driver risk factors and physical road infrastructure that prevents vehicle excursions from the road become crucial interventions. The examination of speed limit reductions highlights the key safety benefits that can be achieved either through elimination of the crash altogether–associated with braking and the wiping off of energy–or through a lower impact speed. Importantly, the results demonstrate that greater benefits can be achieved by larger speed limit reductions; the analysis demonstrates that a reduction from 100 km/h to at least 80 km/h on unprotected roads may be needed to prevent impact energies that are beyond the engineering design envelope, even for late model, five-star vehicles.

6.6 RESULTS: IMPACT OF SPEED LIMIT REDUCTIONS ON EXEMPLAR HEAD-ON CRASHES

Three head-on crashes were used to demonstrate the effect of reduced speed limits (Table 6.2). These three crashes and the speed limit interventions were as follows:

1. Speed limit reductions of 10 km/h and 20 km/h where the speed limit was 60 km/h. The crash occurred on a C-class road after the B-vehicle crossed the centreline and collided with the A-vehicle. Full details are provided in Appendix E.3.1.
2. Speed limit reductions of 10 km/h and 20 km/h where the speed limit was 80 km/h. The crash occurred on a C-class road after the B-vehicle crossed the centreline and collided with the A-vehicle. Details are provided in Appendix E.3.2.
3. Speed limit reductions of 10 km/h, 20 km/h and 30 km/h where the speed limit was 100 km/h. The crash occurred on a C-class road after the B-vehicle overtook another vehicle travelling in the same lane and in doing so moved into the path of an oncoming vehicle. The impact point was the front-right of both vehicles. Details are provided in Section 6.6.1 (below).

Lane Departure crashes, particularly head-on crashes on straight rural roads, were relatively common and were highly injurious (see *ECIS Report 1*). These crashes represent a key prevention target. By exploring a number of speed limit reduction scenarios, the expected benefits in reducing the number of crashes and/or the injury mitigation effect can be seen. An exemplar crash is described here with detail regarding the other two crashes to be found in Appendix E.

6.6.1 Crash scenario: Head-on crash in a 100 km/h speed zone

The crash occurred on a straight section of a sealed undivided C-class road approximately 30 km due-north of central Melbourne. The speed limit was 100 km/h. The road had a single unbroken painted centreline over some of its length and otherwise a single broken painted centreline. Tactile edge lines were present on both sides of the road, with sealed shoulders also present. The road had limited sight distance due to a crest with overtaking not permitted on approach to this point. The surrounding environment was rural residential and farmland.

The crash occurred in the early evening in clear and dry conditions. The crash involved two drivers in a head-on, frontal impact. The A-vehicle driver (sole occupant) was a middle-aged female driving a late-1990s car; the vehicle was not ANCAP rated. The driver was using cruise control. The B-vehicle driver was a mid-30s male driving an early 2000 3-star ANCAP rated large car.

The crash occurred after the B-vehicle driver crossed the centreline to overtake another vehicle travelling in the same lane. This placed the A-vehicle and B-vehicle into direct conflict (Figure 6.23). Both drivers swerved to avoid the crash.

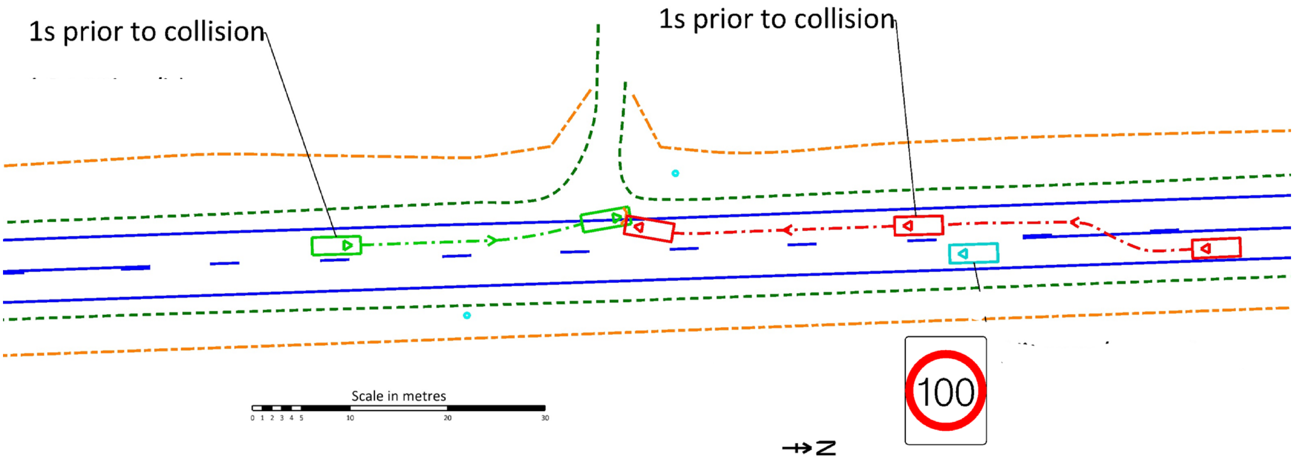


FIGURE 6.7 CRASH LOCATION AND VEHICLE MOVEMENTS

The A-vehicle driver sustained multiple chest injuries (MAIS 5) plus injuries of the upper extremity, the lower extremity, and the pelvis-abdomen. The dual frontal airbags deployed and the seat belt was worn. The driver of the B-vehicle was hospitalised with an MAIS 1 injury severity level.

Based on the crash reconstruction, the travel speed estimate for the A-vehicle was 100 km/h, as was the B-vehicle driver. With both drivers braking and steering to avoid the crash, the A-vehicle velocity at impact was 53.9 km/h and the B-vehicle velocity at impact was 64.4 km/h.

6.6.2 Interventions

The speed reduction measures relevant for both vehicles were:

1. Reduced speed limit from 100 km/h to 90 km/h (- 10 km/h).
2. Reduced speed limit from 100 km/h to 80 km/h (- 20 km/h).
3. Reduced speed limit from 100 km/h to 70 km/h (- 30 km/h).

6.6.3 Crash reconstruction parameters for the intervention scenarios

The A-vehicle was matched by manufacturer, like model, geometry, and mass. The B-vehicle was matched on type, geometry, and mass.

The road surface friction coefficient used was 0.75. The crest of the peak in the road was modelled for the B-vehicle and a 1.5° slope for the A-driver.

6.6.4 Crash outcomes

The damage to both vehicles in the actual crash scenario was extensive (Table 6.5, Figure 6.8) and can be seen graphically in Figure 6.9. The A-vehicle demonstrated significant crush and the steering wheel was pushed rearwards toward the driver. While the airbag deployed, the loss of occupant space was significant between the steering wheel hub and seat-back. The driver sustained multiple serious injuries (see above).

TABLE 6.5 CRASH PARAMETERS FOR THE ACTUAL CRASH AND LOWER SPEED LIMIT SCENARIOS

VEHICLE / SCENARIO	CRASH PARAMETER							
	TRAVEL SPEED (KM/H)	IMPACT SPEED (KM/H)	DELTA-V (KM/H)	IMPACT POINT	PDOF (⁰)	PEAK FORCE (kN)	KINETIC ENERGY (J)	MAXIMUM CRUSH (MM)
A-VEHICLE								
Original crash	**100.0**	**53.9**	**54.9**	**Front right**	**10.5**	**406.5**	**196,528**	**830**
Change in speed limit, main carriageway from 100 km/h								
To 90 km/h	90.0 [-10.0%]	37.1 [-31.2%]	32.2 [-29.8%]	Front right	18.5	174.9 [-57.0%]	92,667 [-52.8%]	680 [-18.1%]
To 80 km/h	80.0 [-20.0%]	32.5 [-39.7%]	14.4 [-29.8%]	Front right (narrow)	26.2	49.5 [-87.8%]	70,839 [-64.0%]	628 [-24.3%]
To 70 km/h	70.0 [-30.0%]	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided
B-VEHICLE								
Original crash	**100.0**	**64.4**	**65.3**	**Front right**	**19.7**	**406.5**	**248,280**	**1727**
Change in speed limit, main carriageway from 100 km/h								
To 90 km/h	90.0 [-10.0%]	45.9 [-28.7%]	36.4 [-44.3%]	Front right	18.8	174.9 [-57.0%]	125,449 [-49.5%]	1411 [-18.3%]
To 80 km/h	80.0 [-20.0%]	31.2 [-51.6%]	15.1 [-76.9%]	Front right (narrow)	33.8	49.5 [-87.8%]	57,973 [-76.7%]	1930 [+11.8%]
To 70 km/h	70.0 [-30.0%]	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided

Note: this is the B-vehicle speed as the 'bullet' vehicle.

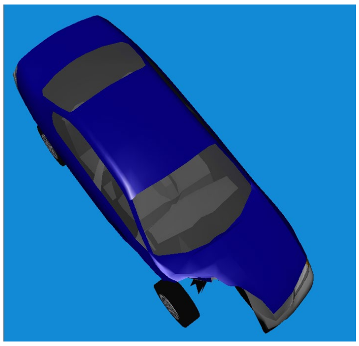
The velocity of the B-vehicle was matched to the frontal offset crash test speed (64 km/h; see Appendix C); the driver sustained MAIS 1 injuries despite significant crush. The vehicle held a 3-star ANCAP safety rating.

In the 90 km/h and 80 km/h speed limit scenarios, the velocity at impact of both vehicles was lower with a significant reduction in the peak force of the crash and the kinetic energy experienced by both drivers/vehicles. The degree of vehicle crush also reduced but increased in the 80 km/h speed limit scenario for the B-vehicle due to a slightly different impact point; this commonly occurs in frontal offset impact crashes, particularly small overlap scenarios due to a lower degree of engagement at impact with the ‘stiff’ structures of the vehicle, including for instance the longitudinal structures that act to absorb force at impact.[102]

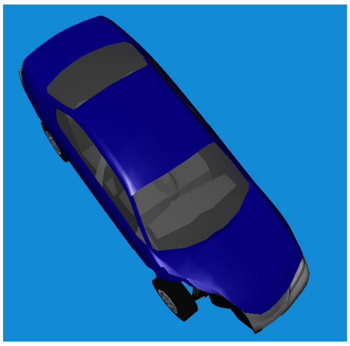
The crash was avoided in the 70 km/h speed limit scenario due to driver avoidance actions on the part of both drivers. These avoidance actions included steering and braking.

A-VEHICLE | B-VEHICLE

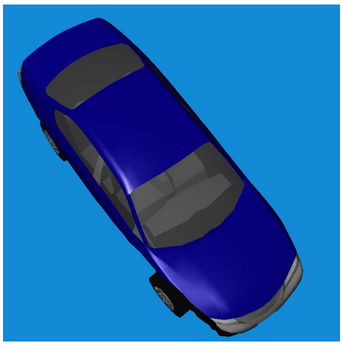
BASELINE CRASH SCENARIO (100 KM/H SPEED LIMIT)



ALTERNATIVE SCENARIO (1): SPEED LIMIT REDUCED TO 90 KM/H



ALTERNATIVE SCENARIO (1): SPEED LIMIT REDUCED TO 80 KM/H



ALTERNATIVE SCENARIO (1): SPEED LIMIT REDUCED TO 70 KM/H

IMPACT AVOIDED | **IMPACT AVOIDED**

FIGURE 6.8 CRASH RECONSTRUCTION REPRESENTATION OF IMPACT DAMAGE

102 Sherwood CP, Nolan JM, Zuby DS. Characteristics of small overlap crashes. Paper No. 09-0423. The 27th International Technical Conference on the Enhanced Safety of Vehicles (ESV); Stuttgart, Germany. 2009. https://www-esv.nhtsa.dot.gov/Proceedings/21/09-0423.pdf. Note: due to the higher injury associated with small overlap, narrow offset crashes, the US IIHS have implemented a narrow-offset crash test. https://www.iihs.org/ratings/about-our-tests/test-protocols-and-technical-information.

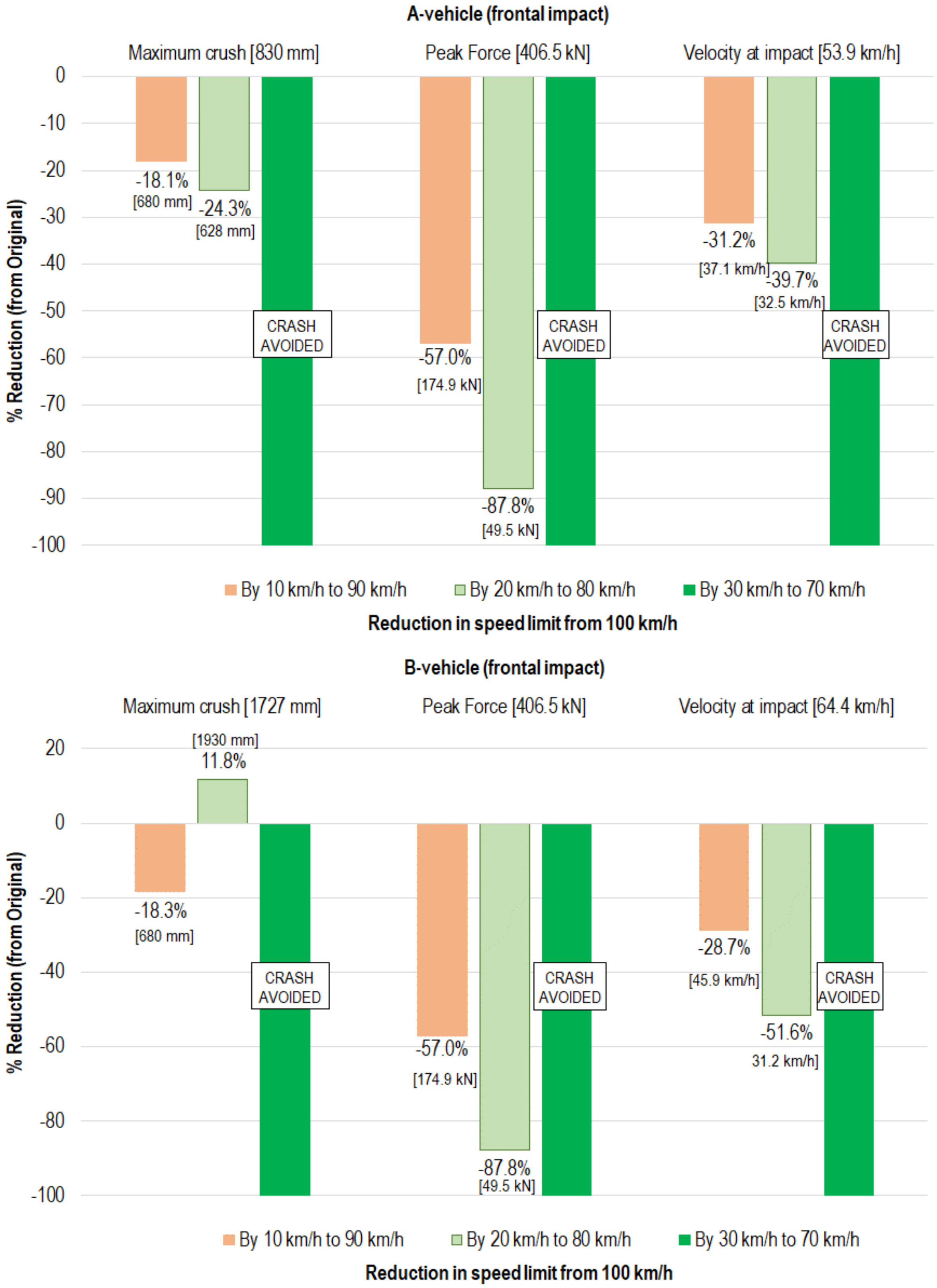


FIGURE 6.9 CHANGE IN MAXIMUM CRUSH, PEAK FORCE, AND IMPACT VELOCITY BY SPEED LIMIT CHANGES FOR THE A-VEHICLE AND THE B-VEHICLE RELATIVE TO ACTUAL CRASH SCENARIO

6.6.5 Interpretation and summary

The crash reconstruction highlighted the high severity impact of the crash in its original form. The injury severity experienced by the A-vehicle driver was very high (AIS 5, chest). This was a consequence of the substantial force of the crash, the associated vehicle crush and loss of occupant compartment space due to the displacement of the steering wheel towards the driver, noting the driver frontal airbag deployed. The A-vehicle was unrated by ANCAP due to it being a late-1990s model, while the B-vehicle held a 3-star ANCAP rating. The B-vehicle driver was travelling at the crash test speed of 64 km/h when the driver side frontal offset crash occurred (see Appendix C for crash test specifications). The mass ratio favoured, to a small degree, the A-vehicle driver (A:B ratio: 1.07).

In the 90 km/h and 80 km/h reduced speed limit scenarios, the vehicle speed at impact was significantly lower. This was reflected in the markedly lower delta-V, force and energy measures and vehicle deformation. This would most likely result in significantly lower risk of MAIS 3+ injuries for the A-vehicle driver, noting that the B-vehicle driver sustained MAIS 1 injuries in the actual crash scenario. The adverse factor in this crash was the poor vehicle crashworthiness of both vehicles, but the A-vehicle in particular. This was reflected in the severity and type of injuries sustained in the crash. Notwithstanding this, the lower speed limit and associated lower crash energy and crush would most likely result in a lower severity injury profile for the A-vehicle driver given the impact speed – injury severity relationship presented in chapter 3 (above).

In the 70 km/h speed limit scenario, the combined driver actions ensured that the crash did not occur. This is important as the additional time and the lower initial velocity enabled the vehicles to avoid impact.

The findings here demonstrate the benefits of reducing the speed limit from 100 km/h, with the 70 km/h speed limit enabling this crash to be avoided due to the avoidance behaviours of both drivers. This speed limit aligns with the criteria of an inherently safe road transport system as presented in *ECIS Report 1* (chapter 8). Injury reduction benefits were also achieved by reducing the speed limit to 80 km/h from 100 km/h. The findings also highlight the interaction between poor vehicle safety and injury outcomes when crashes occur on high-speed zone roads without physical lane separation measures.

6.6.6 Discussion of the outcomes of speed limit reductions as applied to the three head-on crashes

The speed limit reductions as implemented resulted in significantly lower crash metric values and in two scenarios (80 km/h to 60 km/h; 100 km/h to 70 km/h) the crash was eliminated altogether (see Appendix E.3 for detail). The findings highlight the gross mismatch of travel speeds, driven largely to the speed limit settings, and hence, impact speed, and the inability of vehicles to provide adequate protection against serious injury.

Notwithstanding the range of driver actions associated with head-on crashes, the prevention of head-on crashes and the mitigation of injury is perhaps the most straight-forward of all crash types given the simpler vehicle dynamics. The impact of head-on crashes is, by definition, to the frontal structure of the vehicle. Frontal impacts are regarded as the most favourable impact due to the engineered-in vehicle structures; occupant protection features such as airbags and optimised seat belt systems, and the physical space between the occupant seating position and the bonnet edge. However, as shown in the exemplar crashes here, and as documented fully in *ECIS Report 1*, the impact speed of these crashes is characteristically too high, and in many instances is beyond the protection threshold provided by vehicles. As shown in this report (chapter 2, chapter 4, chapter 5), the relationship between the speed limit, driver speed choice, and impact speed is clear. It is also the case that exceeding the speed limit exacerbates the severity of injury sustained and is directly linked to an increased risk of crash-involvement (chapter 3).

From a road safety countermeasure perspective, given the inevitability of head-on impacts and the predictability of serious injury, the physical separation of opposing traffic lanes is required for current speed limits to be maintained. However, in the context of the extensive network of undivided roads in Victoria where head-on crashes are both systematic and common, speed limit reductions–as demonstrated here–are likely to be the only viable choice to prevent serious injury associated with head-on crashes on the Victorian road network in the short-to-medium term. In time, active vehicle safety systems including intervening intelligent speed assist (ISA), lane keep assist (LKA), autonomous emergency braking (AEB) and driver monitoring systems (DMS) will play a more integral role in ensuring the safety of vehicle occupants. For this reason, a concerted effort needs to be made to encourage, through consumer demand and regulation, their fitment into all vehicles. In the interim, speed limit reductions represent a key, if not the principal, road safety countermeasure for the mitigation of serious injury in head-on crashes.

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6.7 RESULTS: IMPACT OF SPEED LIMIT REDUCTIONS ON AN EXEMPLAR REAR-IMPACT CRASH

The effects of speed limit reductions and compliance with the speed limit in a rear-impact crash are described below.

6.7.1 Crash scenario: Rear impact crash in a 70 km/h speed zone

The crash occurred at a signalised intersection approximately 25 km east of central Melbourne.

The crash occurred in clear and dry conditions in the early afternoon on an arterial road with a speed limit of 70 km/h. The crash involved two vehicles. The A-vehicle driver was a middle-aged female driving a late 1990s small SUV (no ANCAP rating). The B-vehicle driver was a middle-aged male driving a mid-2000 medium-sized SUV (ANCAP: 4 stars).

The A-vehicle was stationary with two cars ahead at a red light (Figure 6.10). The B-vehicle driver was travelling in excess of the speed limit and struck the rear of the A-vehicle at an estimated 96.2 km/h. The crash resulted in extensive damage and crush to the rear of the A-vehicle with significant loading of the driver seat (Figure 6.11, Figure 6.12, Table 6.6).

The A-vehicle driver sustained an MAIS 2 injury (vertebral column) and extensive bruising. The B-vehicle sustained frontal damage and the driver was reported as uninjured.

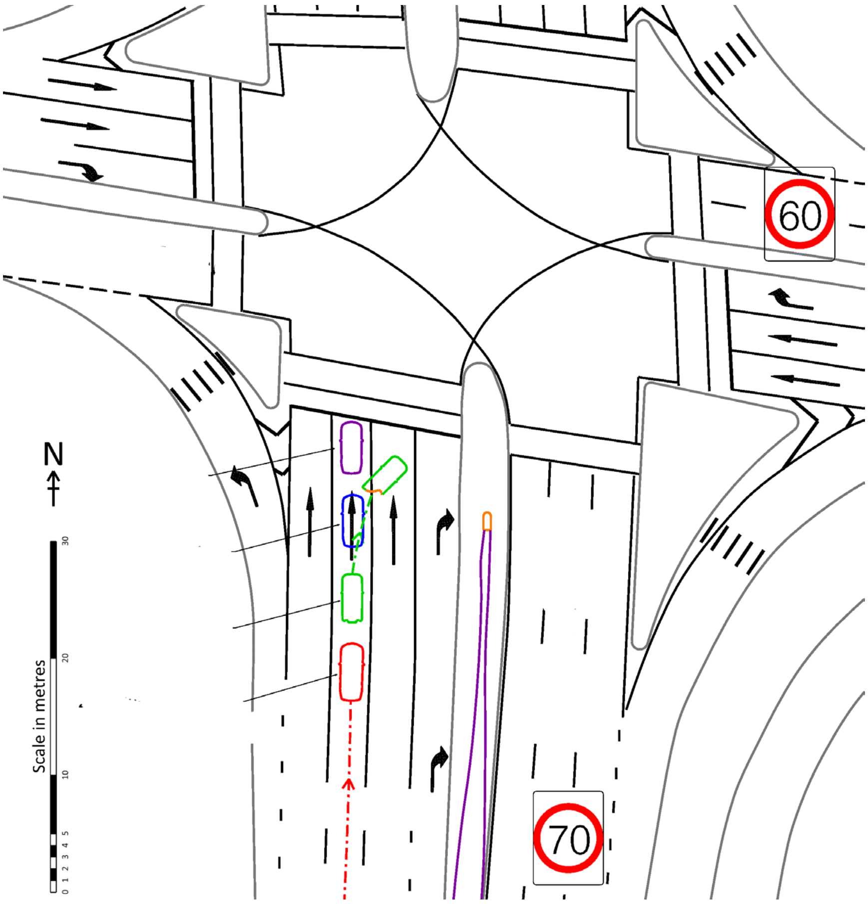


FIGURE 6.10 CRASH LOCATION AND VEHICLE MOVEMENTS

6.7.2 Interventions

Three alternative scenarios were modelled, with these applicable for the speed choice of the B-vehicle driver. The intervention measures were:

1. Compliance speed scenario (B-vehicle at 70 km/h).
2. Reduced speed limit from 70 km/h to 60 km/h (- 10 km/h).
3. Reduced speed limit from 70 km/h to 50 km/h (- 20 km/h).

Under the compliance scenario, the B-vehicle driver was modelled as travelling at the 70 km/h speed limit. In alternative scenarios two and three, the speed limit was modelled at 60 km/h and 50 km/h with B-vehicle driver compliance assumed. The A-vehicle driver was unchanged and remains stationary.

6.7.3 Crash reconstruction parameters for the intervention scenarios

The A-vehicle was matched by type and mass and the B-vehicle was matched by make and model. The roadway friction coefficient was set at 0.80.

6.7.4 Crash outcomes

The damage profiles of both vehicles in the actual crash scenario were extensive. This can be seen in Figure 6.11 with the numerical data presented in Table 6.6 (see also Figure 6.12).

In the compliance scenario with the speed limit unchanged and the two speed limit reduction scenarios, there was a reduction in the crash severity as indexed by the impact velocity, the delta-V and associated force and energy metrics (Table 6.6).

TABLE 6.6 CRASH PARAMETERS FOR THE ORIGINAL CRASH AND LOWER SPEED LIMIT SCENARIOS

VEHICLE / SCENARIO	CRASH PARAMETER							
	TRAVEL SPEED (KM/H)	IMPACT SPEED (KM/H)	DELTA-V (KM/H)	IMPACT POINT	PDOF (⁰)	PEAK FORCE (kN)	KINETIC ENERGY (J)	MAXIMUM CRUSH (MM)
A-VEHICLE								
Original crash	**0.0**	**96.2***	**52.0**	**Rear right**	**168.4**	**361.8**	**0.0**	**691**
Compliance scenario at 70 km/h speed limit								
At 70 km/h	0.0	70.5* [-24.3%]	40.7 [-21.7 %]	Rear right	167.0	321.4 [-11.2%]	0.0	523 [-26.7%]
Change in speed limit, main carriageway from 70 km/h								
To 60 km/h	0.0	60.1* [-46.5%]	34.1 [-34.4%]	Rear right	168.2	294.2 [-18.7%]	0.0	370 [-37.5 %]
To 50 km/h	0.0	50.1* [-52.8%]	29.6 [-43.1%]	Rear right	168.3	231.3 [-36.1%]	0.0	326 [-47.9%]
B-VEHICLE								
Original crash	**96.2**	**96.2**	**46.8**	**Front left**	**-12.1**	**361.7**	**536,892**	**691**
Compliance scenario at 70 km/h speed limit								
At 70 km/h	70.5 [-24.3%]	70.5 [-24.3%]	38.4 [-36.8 %]	Front left	-13.2	321.3 [-11.2%]	288,387 [-46.3%]	514 [-25.6%]
Change in speed limit, main carriageway from 70 km/h								
To 60 km/h	60.1 [-46.5%]	60.1 [-46.5%]	30.8 [-34.2 %]	Front left	-11.7	294.1 [-18.5%]	209,315 [-61.0%]	419 [-39.4%]
To 50 km/h	50.1 [-52.8%]	50.1 [-52.8%]	28.1 [-40.0%]	Front left	-11.2	231.3 [-36.1%]	145,799 [-72.8%]	364 [-52.8 %]

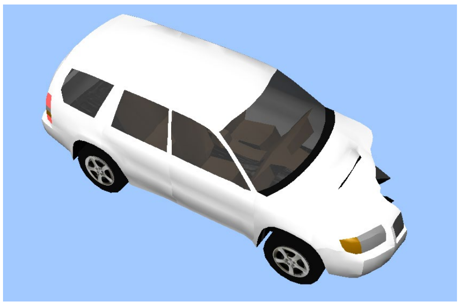
Note: this is the B-vehicle speed as the 'bullet' vehicle.

6.7.5 Interpretation and summary

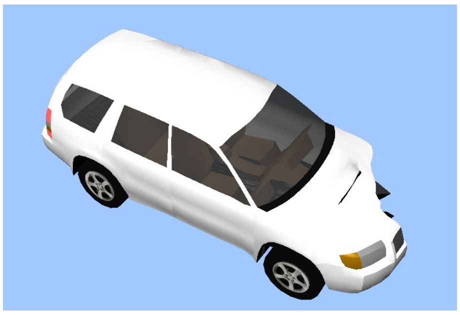
The effect of ensuring speed limit compliance with the 70 km/h speed limit would result in a marked reduction in all key metrics from the actual crash scenario. Even so, the extent of crush remains significant. Lower speed limits and resultant lower impact speeds of 60 km/h and 50 km/h resulted in marked reductions in crash force and energy values compared to those seen in the actual crash scenario. Nonetheless, the probability of the A-vehicle driver sustaining an MAIS 2 injury remains high at these impact speeds while sustaining multiple MAIS 1 injuries would be inevitable. Given the nature of the impact the driver would be considered to be a *potential high acuity patient* and would be transported to hospital. This crash highlights a marked contrast with frontal and side impact crashes at these impact speeds. It is, however, worth noting that there were no rear-seat occupants in this crash. This is critical given the complete loss of the rear occupant compartment space. The lower impact speeds would most certainly provide improved protection for a rear occupant had they been present at the time of the crash.

A-VEHICLE | B-VEHICLE

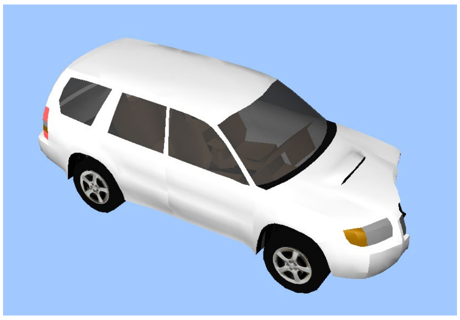
BASELINE CRASH SCENARIO: 70 KM/H SPEED LIMIT AND B-VEHICLE NON-COMPLIANCE



ALTERNATIVE SCENARIO (1): SPEED LIMIT OF 70 KM/H WITH COMPLIANCE



ALTERNATIVE SCENARIO (2): SPEED LIMIT REDUCED TO 60 KM/H WITH COMPLIANCE



ALTERNATIVE SCENARIO (3): SPEED LIMIT REDUCED TO 50 KM/H WITH COMPLIANCE

FIGURE 6.11 CRASH RECONSTRUCTION REPRESENTATION OF IMPACT DAMAGE

FIGURE 6.12 CHANGE IN MAXIMUM CRUSH, PEAK FORCE, AND IMPACT VELOCITY BY SPEED LIMIT CHANGES FOR THE A-VEHICLE AND THE B-VEHICLE RELATIVE TO ACTUAL CRASH SCENARIO

6.8 DISCUSSION

The aim of the case series presented in this chapter was to illustrate the road safety benefit of lower speed limits and speed compliance on crash outcomes and driver injury severity. Using 10 crashes (four in chapter 6, six in Appendix E) across four crash types, the road safety benefits of lower speed limits and associated driver compliance were apparent.

The case series was performed with the view of re-imagining the outcomes of a crash based on changing one parameter, as in most instances drivers were compliant with the speed limit. In conducting these alternative scenarios, the assumption, of course, is that all other factors remain constant. It was expected that by undertaking this analysis a clearer understanding of the beneficial role of lower speed limits and associated compliance can be achieved.

The ECIS program was able to conduct this innovative analysis by making use of the advanced computer crash reconstruction program *HVE*. By modifying validated crash reconstructions of real crashes and making assumptions concerning driver behaviour, it was possible to remodel real crashes to assess the impact on injury severity of reductions in the speed limit.

In all but one of the 24 alternative crash scenarios, benefits were seen across a range of metrics including: collision avoidance (n = 7, 29%); reduced impact speed (n = 16, 67%) with consequent changes in crash energy, as well as changes in the point of impact on the crash-involved vehicles. In only one scenario was the crash outcome worse (4%). This was a case where the 100 km/h speed limit was reduced to 90 km/h; in this case the crash dynamics and the presence of a large number of unprotected trees led to a poorer outcome. However, by changing the speed limit from 100 km/h to 80 km/h the crash would have been avoided altogether. This demonstrates the importance of ensuring speed limit reductions are done through the Safe System lens.

In the instances where crashes occurred but were associated with a lower impact speed, the specific injury reduction effect was not directly stated. However, based on the relationship between impact speed and injury severity described in chapter 5 as well as past research,[103,104,105] it can be expected that these lower travel speeds and consequent impact speeds would deliver substantial injury reduction benefits to the involved driver(s) and other vehicle occupants.

While demonstrating positive results for road safety, it is recognised that the number of crashes examined was small. These exemplar crashes did, however, include a range of vehicle movements and configurations across different speed zones and road types.

For completeness, it is noted that the findings are subject to the assumptions and limitations made in the crash reconstruction itself, as well as in the application of each alternative, hypothetical scenario. This includes assumptions that the driver(s) will respond in the manner as described.

To conclude, the case series presented here provides an objective assessment of the impact of changes in pre-crash driver travel speed as demanded by speed limit reductions. Complete crash avoidance was achieved in 7 of the 24 alternative speed limit scenarios modelled (29%) and in 5 of the 10 crashes (50%) examined, depending on the speed limit reduction scenario. Where crashes continued to occur, they did so at lower impact speeds.

It is hoped that the road safety benefits demonstrated in this case series will be used to motivate the setting of speed limits in line with the Safe Roads criteria outlined in *ECIS Report 1*. Collectively, the findings of this report demonstrate that by aligning speed limits with best practice, substantial reductions in the number of drivers seriously injured (and killed) in Victoria will be achieved over time as the effects of enforcement and acclimatisation to the new speed limits occur.

103 Doecke SD, Baldock MRJ, Kloeden CN, Dutschke JK. Impact speed and the risk of serious injury in vehicle crashes. Accident Analysis & Prevention. 2020;144:105629.
104 Campbell KL. Energy Basis for Collision Severity. SAE Transactions. 1974; 83(3): 2114-2126.
105 Nahum AM, Melvin JW. (Eds.). Accidental Injury: Biomechanics and Prevention. New York: Springer-Verlag; 2002.

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7 PRINCIPAL FINDINGS AND CONCLUDING COMMENTS

The ECIS program set out with two objectives: 1) to provide the TAC with insight into how serious injury crashes occur; 2) to identify crash prevention measures as well as measures that would be effective in preventing occupants of vehicles being seriously injured once a crash occurs. This report addresses the first objective.

This report, the second in the ECIS Report Series, examined the role that speed plays in driving crash risk and in shaping injury severity. The report set out to address five questions, these being:

1. What is the relationship between the speed limit and travel speed?
2. What is the relationship between travel speed and the risk of involvement in a crash that results in one or more involved drivers being hospitalised (referred to as *hospitalisation-severity crash risk)*?
3. What is the relationship between the travel speed of a vehicle and the speed of the (same) vehicle at impact, the frequency of pre-crash avoidance actions and the effect, if any, of these actions on vehicle speed at the point of impact?
4. What is the relationship between impact speed and injury severity?
5. What is the injury reduction benefit of lower impact speeds?

In addition to these five questions, this report sought to illustrate the potential benefits of reduced travel speed, speed limit compliance and reduced impact speed on crash and injury severity outcomes using a case series approach.

Addressing these questions represents a comprehensive examination of the role that vehicle speed plays in regulating the safety of the road transport system. This understanding is central to Vision Zero and the Safe System approach.

It was expected that the insight gained from this analysis will serve as an invaluable input into decisions aimed at eliminating serious injury on the Victorian road transport system.

The findings were presented across five chapters. The principal findings are as outlined below (see Figure 7.1).

7.1 THE ROLE OF THE SPEED LIMIT IN DETERMINING TRAVEL SPEED

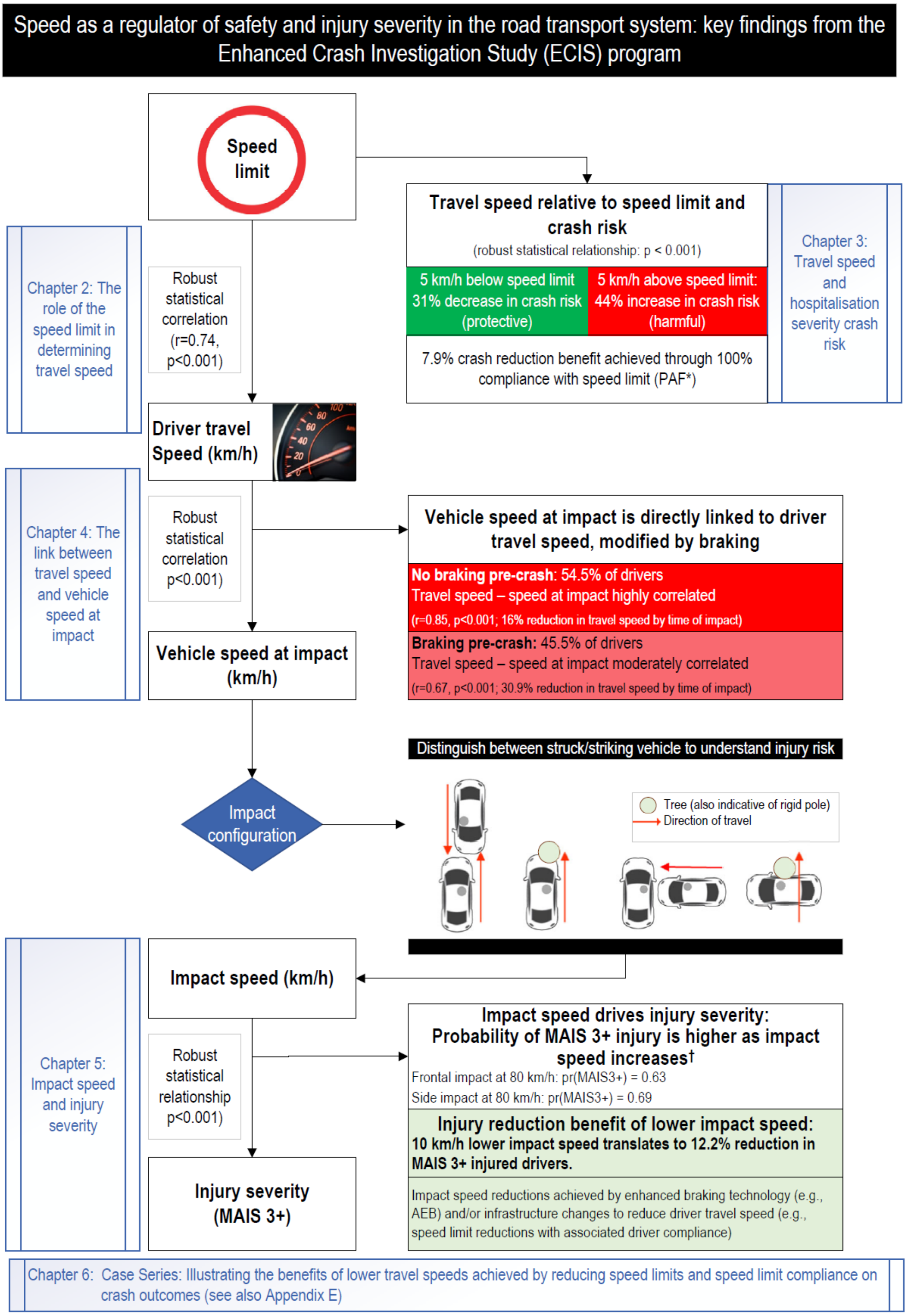
The primary analysis question for chapter 2 was: *What is the relationship between the speed limit and travel speed?* This analysis also enabled the reporting of the proportion of drivers exceeding the speed limit among a large sample of drivers.

Driver speed choice was examined through the correlation between speed limits and travel speed. Using travel speed data from 2,180 drivers, a high correlation was found ($r = 0.738$, $p < 0.001$). The mean and median speed choice of drivers tracked closely to the speed limit across all speed zones, with data presented for speed limits ranging from 50 km/h to 110 km/h. This relationship can be seen in Figure E.1.

The data also showed that 15.0% of drivers were exceeding the speed limit by 3 km/h or more. However, differences were evident across speed limit zones, with 38.1% of drivers exceeding the speed limit by 3 km/h or more in 70 km/h zones. In contrast, 8.1% of drivers in 100 km/h zones were exceeding the speed limit by 3 km/h or more. The proportion of drivers exceeding the speed limit by 5 km/h or more was 10.3% with differences across speed limit zones evident.

PRINCIPAL FINDINGS	
1	Driver travel speed was highly correlated with the speed limit (r = 0.738). The mean and median travel speed reflected the speed limit across all speed zones.
2	The proportion of drivers exceeding the speed limit by 3 km/h or more was 15.0% and 10.3% of drivers were exceeding the speed limit by 5 km/h or more. There were differences in the proportion of drivers exceeding the speed limit across speed limit zones, with the lowest levels of non-compliance being in 80 km/h zones and higher. The highest level of non-compliance was seen in 70 km/h zones (≥ 5 km/h: 28.4%), followed by 60 km/h zones (≥ 5 km/h: 14.6%), and 50 km/h zones (≥ 5 km/h: 8.5%).

This analysis represents the first link in the chain of the role of speed and the importance of speed limits in shaping driver behaviour. The findings demonstrate a high degree of driver compliance, this being important from a number of perspectives, in particular, that speed limit changes would be highly likely to result in a shift in driver behaviour. Nonetheless, that a proportion of drivers fail to obey the speed limits highlights a role for continued enforcement and opens up the prospect of active vehicle safety systems, such as Intelligent Speed Assist (ISA), playing a role in ensuring safe driver behaviour.



Notes: *PAF: population-attributable fraction; r: correlation coefficient; †based on ECIS sample of hospitalised drivers; pr: probability; AEB: auto-emergency braking
Source: Fitzharris et al. ECIS Report 2: Speed, crash risk and injury severity. Report 344. Monash University Accident Research Centre: Clayton. https://www.monash.edu/muarc

FIGURE 7.1 PRESENTATION OF KEY FINDINGS

7.2 THE RELATIONSHIP BETWEEN TRAVEL SPEED AND HOSPITALISATION-SEVERITY CRASH RISK AND THE BENEFITS OF ELIMINATING SPEEDING

Two key questions were asked in the analysis of travel speed and crash involvement, as reported in chapter 3:

1. What is the relationship between travel speed and crash risk? As the ECIS program was focussed on hospitalised drivers, the crash risk examined here is correctly stated to be the risk of being involved in a crash where one or more involved drivers was hospitalised. For the purposes of brevity, this is referred to as 'crash risk' or 'hospitalisation-severity crash risk'.
2. What are the crash reduction benefits of 100% driver compliance with the speed limit?

The analysis demonstrated that travel speed was associated with *crash risk* and that this association was statistically significant ($p < 0.001$). Driving in excess of the speed limit was associated with a higher crash risk. Conversely, travelling below the speed limit had a protective effect and was associated with a lower crash risk. This was the case for all crashes, as well as when the analysis was limited to Lane Departure crashes and Across Path crashes.

For instance, across all crashes, for every 1 km/h travelling above the speed limit, the relative risk of being involved in a hospitalisation-severity crash increases by an estimated 7.6%, adjusted for driver age and driver sex (RR: 1.08, 95% CI: 1.06 – 1.10, $p < 0.001$).

For low level speeding – defined as driving 3 km/h above the speed limit – the increased crash risk was estimated to be 25%; the 95% confidence intervals estimate that this increased risk could be as low as 18% or as high as 32% (RR: 1.25, 95% CI: 1.18 – 1.32). Drivers travelling 5 km/h above the speed limit had an estimated 1.44 times higher crash risk than that of drivers travelling at the speed limit; this equates to a 44.4% increased crash risk (95% CI Range = +31.1% to +59.4%; RR: 1.44, 95% CI: 1.31–1.59). Hence, it can be stated that driving at 5 km/h above the speed limit was associated with a 44.4% increase in crash risk compared to driving at the speed limit.

For drivers travelling 10 km/h above the speed limit the crash risk was estimated to be more than double (i.e., twice) that of drivers travelling at the speed limit (+108.5%; RR: 2.09, 95% CI: 1.72–2.53). Driving 15 km/h above the speed limit was associated with a crash risk triple that of drivers travelling at the speed limit (+201.1%; RR: 3.01, 95% CI: 2.26–4.01).

The protective effect of driving below the speed limit was also evident with, for example, drivers travelling 5 km/h below the speed limit having a crash risk 0.69 times that of drivers travelling at the speed limit, translating to an estimated 30.8% lower risk of being involved in a hospitalisation severity crash (RR: 0.69, 95% CI: 0.63 – 0.76). The protective effect of travelling below the speed limit was greater with travel speeds further below the speed limit. For instance, the crash involvement risk was 52.0% lower for drivers travelling 10 km/h (RR: 0.48, 95% CI: 0.40–0.58) and 67.5% lower for drivers travelling 15 km/h below the speed limit (RR: 0.33, 95% CI: 0.25–0.44).

The analysis presented in the body of the report also highlights the increased crash risk of young drivers (18 – 25 years of age), older drivers (76+ years of age) and male drivers.

The analysis examined the crash reduction benefit that could be achieved by ensuring 100% compliance with current speed limits. The calculation of the Population Attributable Fraction (PAF) estimated that 7.9% reduction in the number of hospitalisation crashes could be achieved by eliminating speeding behaviour.

PRINCIPAL FINDINGS	
3	Travel speed was associated with the risk of being involved in a crash where one (or more) involved driver required hospitalisation for injuries sustained. Driving in excess of the speed limit was associated with a higher crash risk while conversely travelling below the speed limit had a protective effect and was associated with a lower crash risk. This relationship was seen individually in Lane Departure crashes and Across Path crashes, as well as in all crashes combined. By way of example, drivers travelling 5 km/h above the speed limit had an estimated 1.44 times higher crash risk than that of drivers travelling at the speed limit. In percentage terms, this is interpreted as driving at 5 km/h above the speed limit was associated with a 44.4% increase in crash risk compared to driving at the speed limit. Travelling 5 km/h below the speed limit was associated with an estimated 30.8% lower crash risk than drivers travelling at the speed limit.
4	Young drivers (18 – 25 years of age), older drivers (76+ years of age) and male drivers had a higher crash involvement risk than other aged drivers and females.
5	Nearly one-fifth of crash-involved drivers were exceeding the speed limit prior to the crash (18.6%), with this being higher for drivers involved in Lane Departure crashes (27.0%) than for Across Path crashes (11.4%). The proportion of drivers exceeding the speed limit was higher among drivers who were involved in a crash than those who were not. That the vast majority of drivers were complying with the speed limit yet were seriously injured underscores the inadequacy of current speed limits in protecting drivers in the event of a crash. This points to the need to better match speed limits with the available road infrastructure whilst being cognisant of the level of protection afforded by vehicles. This point was addressed in detail in *ECIS Report 1*.
6	The elimination of speeding behaviour using speed limits as currently set would result in a 7.9% reduction in the number of hospitalisation crashes. This calculation was statistically adjusted for driver age and driver sex and excludes crashes where an involved driver had consumed alcohol and/or had used illicit drugs (AOD). Hence, this 7.9% reduction estimate in hospitalisation crashes does not include crash-involved drivers who had used AOD and who were exceeding the speed limit.

7.3 THE LINK BETWEEN TRAVEL SPEED, VEHICLE SPEED AT IMPACT AND PRE-CRASH AVOIDANCE ACTIONS

Two key questions were asked in the analysis of travel speed and impact speed, as reported in chapter 4:

1. What is the relationship between travel speed and the speed of vehicles at impact?
2. What proportion of drivers engaged in pre-crash avoidance behaviours and what was the effect, if any, on the relationship between travel speed and vehicle speed at impact?

Using the data derived from the crash reconstruction process, 54.5% of drivers involved in Lane Departure crashes and Across Path crashes braked prior to the crash, however braking was more common in higher speed limit zones. Steering avoidance manoeuvres were more common among drivers who braked (45.7%) than those who did not (10.9%). Differences in pre-crash braking and steering actions were evident across Lane Departure crashes, Across Path crashes and Rear Impact crashes.

Vehicle speed at impact was correlated with travel speed, as expected; however, this was modified by driver braking (Table E.2). This is seen by the magnitude of the correlation coefficient (r) being larger where drivers did not brake ($r = 0.86$, $p < 0.001$) than where braking was applied ($r = 0.67$, $p < 0.001$); this result simply reflects the effect of braking in reducing vehicle speed.

The principal finding is the robust correlation between travel speed and vehicle speed at impact. Per *ECIS Report 1*, the time under braking was short, resulting in there being insufficient time to avoid the crash. Steering avoidance actions were also insufficient in preventing these crashes. Combined with the previous finding that speed choice (i.e., travel speed) is driven by the speed limit, this finding provides a key link between the speed limit and impact speed.

PRINCIPAL FINDINGS	
7	Vehicle speed at impact was highly correlated with travel speed, the strength of the correlation being modified by the presence of braking.
8	Approximately half (54.5%) of all drivers braked immediately prior to the crash, ‘wiping-off’ slightly less than one-third (-30.9%) of travel speed.

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7.4 THE RELATIONSHIP BETWEEN IMPACT SPEED AND SERIOUS INJURY AND THE BENEFITS OF LOWER IMPACT SPEEDS

The relationship between impact speed and MAIS 3+ (serious) injuries was examined. This enabled the assessment of the potential benefits of reduced travel speed and impact speed on crash and injury severity.

The analysis demonstrated a direct relationship between impact speed and MAIS 3+ injury. As expected, the probability of a driver sustaining an MAIS 3+ injury was higher as impact speed increased. This was seen in both frontal and side impact crashes.

This relationship was used as the basis for assessing the safety benefit associated with a 5 km/h reduction in impact speed and a 10 km/h reduction in impact speed. The analysis indicated that a 6.3% reduction in the percentage of hospitalised drivers sustaining MAIS 3+ injuries involved in frontal and side impact crashes could be achieved through a 5 km/h reduction in impact speed. This benefit increases to a 12.2% reduction given a 10 km/h reduction in impact speed. The benefit was higher for frontal impact crashes than for side impact crashes.

It was stated in the report that these reductions could be achieved on a population-level more rapidly by reducing speed limits—supported by sustained enforcement and public education—given the time lag between widespread adoption and penetration of key vehicle safety systems and the upgrade of existing road infrastructure to the required Safe Roads standard.

PRINCIPAL FINDINGS	
9	Impact speed was associated with sustaining serious MAIS 3+ injuries, with injury risk increasing with higher impact speeds. A 6.3% reduction in hospitalised drivers sustaining MAIS 3+ injuries in frontal and side impact crashes could be achieved through a 5 km/h reduction in impact speed. This benefit increases to a 12.2% reduction given a 10 km/h reduction in impact speed.

7.5 A CASE SERIES APPROACH TO ILLUSTRATING THE EFFECT OF SPEED LIMIT CHANGES ON CRASH OUTCOMES USING CRASH SIMULATION MODELLING

To illustrate the practical effect of speed limit reductions, a series of 'what if' alternative scenarios were modelled using crash reconstruction computer software. Speed reduction measures of -10 km/h, - 20 km/h and -30 km/h were applied, depending on the speed limit, to a selection of 10 ECIS crashes. In each case, speed compliance was assumed given the behaviour of the crash-involved drivers in the actual crash or was forced if a driver was not complying with the speed limit in the actual crash scenario.

Alternative speed limit and compliance scenarios were applied to three intersection crashes, three single-vehicle run-off-road crashes, three head-on crashes, and one rear impact crash. This built on the peer reviewed research that examined the benefits of speed limit changes and infrastructure measures on the outcome of a high speed rural Across Path crash.[106]

The analysis demonstrated that complete crash avoidance was achieved in 6 of the 24 alternative speed limit scenarios modelled (25%) and in 5 of the 10 crashes (50%) examined depending on the speed limit reduction scenario.

For scenarios where crashes would continue to occur, the lower travel speed was associated with lower impact speeds; this was the case in 16 alternative crash scenarios. As a consequence of the lower impact speeds, the involved driver(s) and other vehicle occupants (where applicable) would be exposed to lower levels of mechanical and inertial forces from which injury results. Given the established relationship between impact speed and the probability of sustaining MAIS 3+ injury, the injury reduction benefit of these reduced speed scenarios would be significant.

PRINCIPAL FINDINGS	
10	Applying alternative speed limit scenarios to 10 real-world crashes using crash reconstruction, it was found that half of the crashes would be avoided where lower travel speeds reflect lower speed limits, assuming all other factors stayed constant. In scenarios where crashes still occurred the impact speed and associated crash forces and vehicle deformation were estimated to be lower, directly translating to a lower risk of serious injury.

106 Peiris S, Corben B, Nieuwesteeg M, Gabler HC, Morris A, Bowman D, et al. Evaluation of alternative intersection treatments at rural crossroads using simulation software. Traffic Injury Prevention. 2018;19(sup2):S1-S7.

The case series demonstrates the positive benefit of speed limit reductions and associated driver compliance in reducing the occurrence of crashes and the severity of those that continue to occur. On this latter point, and where crashes continue to occur, the road trauma benefit is driven by lower impact speeds. The case series highlights an important point: while any reduction in speed limits will have a positive benefit on road safety, small speed limit reductions were largely insufficient to bring the impact speed of the crash within the safety envelope of the vehicle; this was especially the case in 90 km/h and 100 km/h speed zones. Given the predictability of crashes and the serious injury outcomes, the critical importance of setting speed limits appropriately cannot be overstated.

The case series serves to highlight the critical links between the speed limit, driver speed choice, impact speed and injury severity. In doing so, the road safety benefits of lower, and appropriately set, speed limits were evident. As stated in this report and in *ECIS Report 1*, speed limits need to be guided by best practice, cognisant of the inherent safety of available road infrastructure and the safety provided by vehicles to occupants in the event of a crash. While the setting of speed limits to appropriate levels is an essential step for reductions in serious injury to be achieved in Victoria, for the full trauma reduction savings of these lower speed limits to be realised, full compliance with these speed limits must be achieved. This level of compliance can be prospectively achieved through a combination of enforcement, the widespread adoption of advanced active vehicle safety systems, the promotion of driver compliance through road design, and the energy management attributes of system-based road infrastructure solutions.

7.6 ASSUMPTIONS, LIMITATIONS AND APPLICATION OF FINDINGS

The analysis and findings presented here are subject to a number of assumptions and limitations. These are stated, as appropriate, within each chapter.

As outlined in detail in *ECIS Report 1*, the ECIS program was designed to be a study of hospitalised drivers subsequent to involvement in a crash. It is therefore important that the findings of this report are viewed and communicated with this in mind. Specifically, the findings are most applicable to crashes involving passenger vehicles where at least one driver was hospitalised, noting that the ECIS sample was biased towards the more serious end of the road trauma spectrum with close to half (47%) of all enrolled ECIS drivers sustaining MAIS 3+ ('serious') injuries (see *ECIS Report 1* for detail).

7.7 CONCLUDING COMMENT

This report set out to examine the role that speed plays in driving crash risk and in shaping injury severity. The findings provide an integrated and comprehensive examination of the role that speed plays in the occurrence and severity of crashes. The findings demonstrate a direct correlation between the speed limit and driver travel speed, while a robust association between travel speed and hospitalisation-severity crash risk was found. With travel speed shown to be linked to the vehicle speed at impact, and impact speed linked to injury severity, the regulating role that the speed limit plays in the level of safety of the road transport system is clear and indisputable. These links are central to the *Vision Zero Model of a Safe Road Transport System* and underpin the *Safe System* approach.

With the goal being the elimination of death and serious injury, the findings provide the basis for a shift in the way speed limits are set. This is reinforced by the finding that crash impact speeds are well beyond the safety limit of vehicles to provide protection for drivers and other occupants, even for many drivers compliant with the speed limit.

The results provide an important foundation on which the implementation of speed-related road safety measures across the *Safe Driver(s), Safe Vehicle(s) and Safe Road(s)* Safe System pillars can be based. These measures include: the appropriate matching of speed limits to the surrounding road environment (Safe Roads) given the safety performance limits of vehicles (Safe Vehicles) and the composition of the passenger vehicle fleet in Victoria; ensuring driver compliance with the speed limits and other requirements (Safe Drivers), and ensuring that enhancements in active and passive vehicle safety not only continue but that the implementation of these measures and the penetration of *Safe Vehicles* into the vehicle fleet are sped up. By adopting this *Safe System* approach and working concurrently across all three elements of the road transport system, the negative role that speed plays as the primary aetiological agent of injury can be addressed.

To conclude, the findings of this research are emphatic: speed plays a fundamental role in determining the safety of the road transport system. This report demonstrates a very clear relationship between the speed limit and driver travel speed, travel speed and vehicle speed at impact, impact speed and injury severity, as well as the negative consequences of drivers exceeding the speed limit. In seeking to reduce, and ultimately eliminate serious injury on our roads, taking the opportunity to address the role that speed plays in driving road trauma is imperative.

APPENDIX A DERIVATION OF TRAVEL SPEED THROUGH CRASH RECONSTRUCTION

The reader is referred to *ECIS Report 1* (chapter 2, Appendix B) for a full description of the ECIS Case Study method. The method used to derive travel speed is described below. This is provided to supplement the material provided in the *Method* section (2.2) of chapter 2.

Two computer-based crash reconstruction approaches were used to estimate the travel speed and impact speed of vehicles involved in each crash (Table A.1). These were defined as Type-A and Type-B. MUARC undertook research and development before adopting these two approaches including validation against EDR data as a reference standard.[107]

All information gathered by the ECIS Case Team was used as the basis of the crash reconstruction process. Inputs included materials relating to the crash event and details of the vehicle(s) involved. Vehicle damage and vehicle rest positions were matched in the virtual crash with the real-world crash.

The difference in the two approaches relates to how the crash scene environment was modelled within the crash reconstruction software. In the Type-A reconstruction, the scene was modelled in 3D whereas in the Type B reconstruction the crash scene was modelled using a 2D planar surface. The 3D environment had significantly greater complexity than the 2D model; however, the latter was used in simple geometry scenarios where the influence of the terrain on vehicle dynamics was absent or negligible.

TABLE A.1 DESCRIPTION OF CRASH RECONSTRUCTION METHODS USED IN ECIS

INPUT FACTOR	CRASH RECONSTRUCTION TYPE	
	TYPE-A	TYPE-B
Crash scenario / narrative	All available information used as inputs.	As per Type-A.
Vehicle	Matched to real-world crash-involved vehicle(s). If the exact vehicle match was not available in HVE or PC-Crash, a similar vehicle in class was used matched on geometry. Adjusted to be of the same vehicle mass, and vehicle occupant mass included.	As per Type-A.
Environment	Modelled using **3D** mesh surfaces. Road geometry and terrain modelled in detail, including use of surface dependent friction coefficient values relevant to the vehicle path.	Modelled using a **2D** planar surface. Single friction coefficient used based on road condition (per published tables). Roadway slope and camber less than 3° not modelled as influence on vehicle dynamics and speed estimation was considered negligible.
Impact	All vehicle damage was matched to the real-world vehicle inspection (i.e., PDOF, CDC). All impacts included. Outputs of the 'virtual' crash model used for visual match and objective damage values.	As per Type-A.
Rest position	Matched to real-world rest position.	As per Type-A.

The crash reconstruction software packages used were *HVE* V.11.2 and PC-Crash v.10.2 with the road environment created using CAD-based software, Rhinoceros V5. (See *ECIS Report 1*, chapter 2, *Method* for more detail, as well as *ECIS Report 1*, Appendix B).

107 Peiris S, Fitzharris M. Examination of crash reconstruction methods and speed estimation concordance with EDR captured speed data. Clayton: Monash University Accident Research Centre; 2017.

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APPENDIX B ECIS CONTROL STUDY METHOD

This material is presented to give the reader additional detail regarding the Control drivers/vehicles associated with the 146 crashes included in the analysis presented in chapter 2. This complements the information provided in *ECIS Report 1* (Appendix C) where details of all Case-Control sites and Control drivers/vehicles were reported.

B.1 DESIGN CONSIDERATIONS IN THE COLLECTION OF ECIS CONTROL DATA

The ECIS Control Arm measured the 'free' speed of vehicles passing through known crash locations. This was done as a key goal of the ECIS program was to examine the association, if any, between travel speed and crash risk (chapter 2, this report).

'Free speed' was defined as the unimpeded travel speed of the driver. In practice, this meant that the first vehicle in a flow of traffic (if present) was measured using the LaserCam4 device (see chapter 2, *ECIS Report 1*). Data validation ensured that the observed driver did not alter their speeds in response to the presence of the ECIS Technical Officer. Where this occurred, these observations were deleted.

In order to achieve the best match of traffic and lighting and conditions at the time of the ECIS crash of interest, speed measurements were taken within a 30-minute window either side of the known crash time, on the same day of the week. Hence, one full week from the time of the crash had to pass before the site became viable as an ECIS Control Site. A critical consideration in the time to complete the Control observations was the time from the crash and resultant hospitalisation until the time of enrolment of the injured driver into the ECIS Case study.

By way of example, if the ECIS crash of interest occurred on a Saturday at 17:00 at a time it was raining, the control vehicle speed measures were taken within a 30-minute window of 16:30 to 17:30 on the next available Saturday. This was an important step to ensure maximum comparability with traffic volume and driver speed choice behaviour. Historical weather records from the Bureau of Meteorology were used to assess the match of the site details given the timing of the crash and the control observations.

Following office-based data collation processes, the owner of the registered vehicle was sent the ECIS Control Study Questionnaire (as outlined in chapter 2, *ECIS Report 1*).

B.2 DATA COLLECTION SITES: NUMBER AND MEASUREMENT TIME SINCE CRASH

B.2.1 Number of ECIS Control Sites

In the analysis set, 146 crashes were used. The majority of crashes occurred in daytime hours (n = 119, 81.5%) and 6 (4.1%) occurred at dawn. There were 14 crashes at night (9.6%) and 7 at dusk (4.8%). Control site observations were matched to these crash times.

B.2.2 Timing of data collection

The time to complete the site observations and speed measurements for the 146 crashes is shown in Table B.1. Slightly more than half (56.8%) of the Control Site visits were undertaken within 4-weeks of the crash, with 82.1% being undertaken within 8-weeks of the crash. As the site becomes viable as an ECIS Control site after consent and enrolment of the injured ECIS Case Driver, the time to attend the site is also shown.

TABLE B.1 DISTRIBUTION OF MEASURED FREE TRAVEL SPEED AT CRASH LOCATIONS

TIME TO SPEED MEASUREMENT†	DAY NUMBER POST-CRASH FOR ECIS CONTROL SITE VISIT (VIABLE DAY)+	TIME FROM ECIS DRIVER CRASH TO CONTROL SPEED OBSERVATIONS		TIME FROM ECIS CASE DRIVER CONSENT TO CONTROL SPEED OBSERVATIONS	
	MATCHED WEEKDAY	NUMBER	%	NUMBER	PERCENT
Within 2 weeks	7, 14	37	25.3%	44	32.0%
3 to 4 weeks	21, 28	46	31.5%	48	27.2%
5 to 8 weeks	35, 42, 49, 56	37	25.3%	31	23.2%
9 – 12 weeks	63, 70, 77, 84	10	6.8%	7	5.3%
> 12 weeks	91, 98, 105, 112	16	11.0%	16	11.0%

† Number of weeks reflects the number of possible opportunities to perform day of week and weather-matched control site observations.

B.3 COMPARABILITY OF ROAD CONDITIONS AND TRAFFIC VOLUME AT THE TIME OF THE ECIS CRASH AND ECIS CONTROL SITE MEASURES

Potential factors that may influence speed choice are described below.

B.3.1 Time and day of week comparability

ECIS Control observations were taken within 30 minutes of the known crash time on the same day of the week. This was done to achieve the best match of traffic conditions, and hence driver speed choice, at the time of the ECIS crash of interest.

In one instance, the ECIS Crash occurred on a public holiday whereas the ECIS Control observations were captured on a normal working day. Due to this difference, it might be anticipated that the travel speed of the vehicles involved in the crash would be faster than control vehicles due to lower traffic volume. However, as the crash occurred on a high-speed low volume rural road it was considered appropriate to include these observations in the analysis; for completeness, the traffic volume on the working day was 3 vehicles per minute in both directions. The control measures were taken two weeks after the crash had occurred and were matched on weather and road conditions. Of note was that the travel speed of the A-vehicle was estimated to be 4 km/h below the median A-vehicle control speed and the crash-involved B-vehicle was estimated to be travelling within +0.5 km/h of the median B-vehicle control speed; this is contrary to what might be expected given the crash occurred on a public holiday. It is considered that the high-speed low volume nature of the road and its rural location negates the potential issue of the public holiday impacting traffic volume, and hence speed choice.

B.3.2 Road condition comparability and weather conditions

Whilst every effort was made to do so, it was not always possible to match the weather and road conditions (wet, dry) at the time of the crash (Table B.2).

Road conditions were matched in 69.2% (n = 101) of Case: Control match sets.

For 20.5% (n = 30) of match sets, the road was wet at the time of the crash but dry during the control observations. This could mean either that the measured control speed was possibly faster due to weather conditions influencing driver speed choice alone – in which case the relationship between travel speed and crash risk would be an under-estimate, and/or the wet road was a risk factor for the crash, all other factors being equal.

In contrast, for 10.3% (n = 15) of match sets the road was dry at the time of the crash and wet during the Control measures. If road condition impacted driver speed choice, with the control speed being slower, the crash risk relationship would be over-estimated.

TABLE B.2 MATCHING OF ROAD CONDITIONS AT THE TIME OF THE CRASH AND THE CONTROL MEASURES

ROAD CONDITIONS	SCENARIO (CASE: CONTROL)	IMPLICATION ON SPEED CHOICE, HENCE CRASH RISK ESTIMATE FOR COMPARABILITY	PERCENT (NUMBER) OF CASE: CONTROL CRASH MATCH SETS IN SCENARIO
Matched	Dry/Dry or Wet/Wet	No influence	69.2% (101)
Not matched	Wet/Dry	Control vehicle speed possibly faster: under-estimate crash risk	20.5% (30)
Not matched	Dry/Wet	Control vehicle speed possibly slower: over-estimate crash risk	10.3% (15)

B.3.3 Road comparability, roadworks, and signage

Before selection as an ECIS Control Site, each potential Control Site was assessed to determine whether any structural changes to the road environment had occurred at the crash scene since the time of the crash. This was done using a combination of photographs of the crash (where available), NearMap (to see historical changes) and the ECIS Crash Scene Inspection on occasions where this was done before the Control observations. This was an important step to ensure comparability of measured speeds.

No structural changes were apparent at the time the Control observations were taken compared to the time of the crash, nor were any roadwork signs evident at either the time of the crash or at the time the Control observations were taken. This was also the case for instances where the Control observations were taken beyond 8 weeks of the crash.

B.4 CONTROL SITE VEHICLE OBSERVATIONS AND DRIVER QUESTIONNAIRES

For the 146 crashes used in the Case-Control analysis, the travel speeds of 3,123 Control drivers were recorded. Of these, 1,039 returned the completed survey to the ECIS Team and 2084 did not; hence, the response rate was 33.2% (of 3123).

For both 'responders' and 'non-responders', the majority of drivers were travelling at or below the speed limit although this was lower for drivers where the index crash was a Lane Departure crash compared to drivers associated with Across Path crashes (Figure B.1, Figure B.2, Figure B.3).

Across all crashes and using the travel speed categories of travelling at or below the speed limit, 1.0 – 4,9 km/h above the speed limit, 5.0 – 9.9 km/h above the speed limit, 10 – 14.9 km/h above the speed limit, and 15+ km/h above the speed limit, the proportion of drivers exceeding the speed limit did not differ between responders (15.2%) and non-responders (14.3%), $X^2(1) = 0.42$, p = 0.5 (Figure B.1). Notably, the proportion of drivers exceeding the speed limit was higher among responders than non-responders (+ 0.9%).

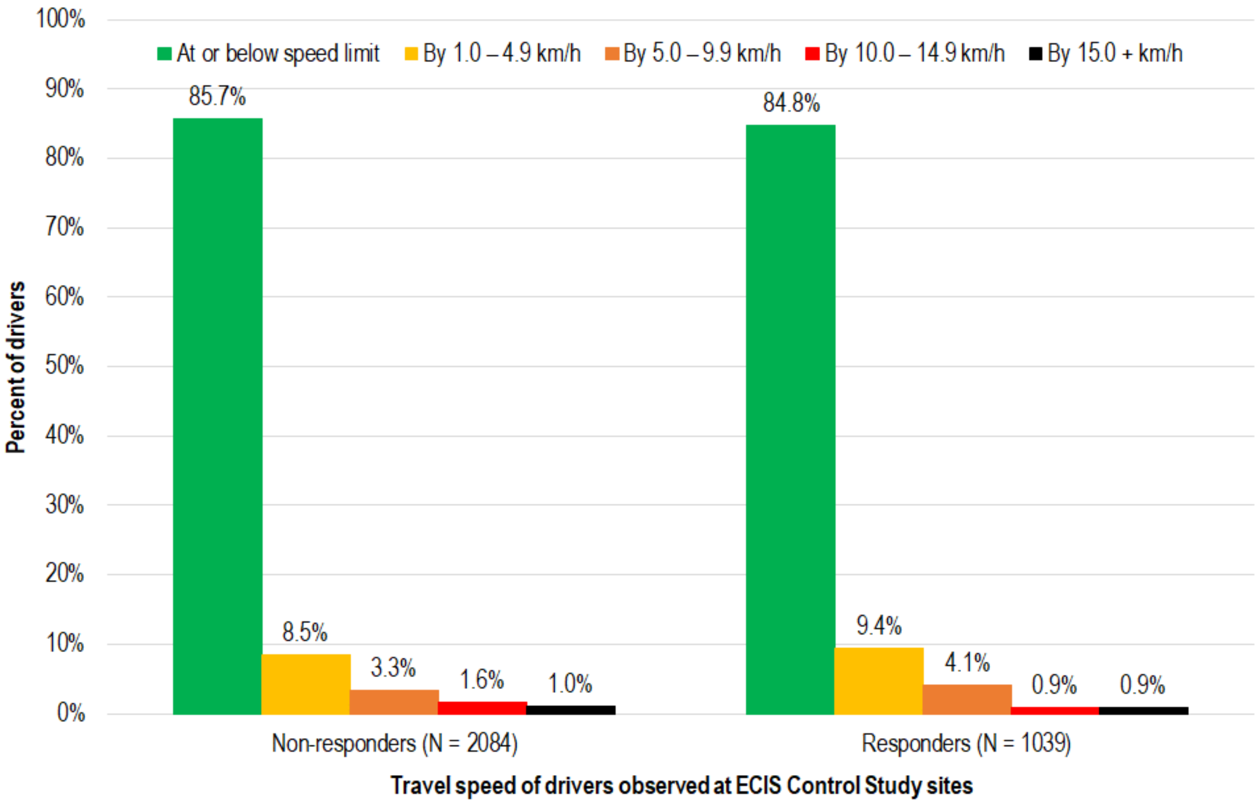

FIGURE B.1 DISTRIBUTION OF MEASURED FREE TRAVEL SPEED AT CRASH LOCATIONS (ALL CRASHES)

For Control drivers associated with Lane Departure crashes, 22.5% of responders and 21.5% of non-responders were recorded as exceeding the speed limit (+1.0%), with this difference not being statistically significant, $X^2(1) = 0.84$, p = 0.3 (Figure B.2).

For Control drivers associated with Across Path crashes, the proportion of responders exceeding the speed limit was lower (7.3%) compared to non-responders (9.1%), although this difference (-1.8%) was not statistically significant, $X^2(1) = 1.48$, p = 0.2 (Figure B.3).

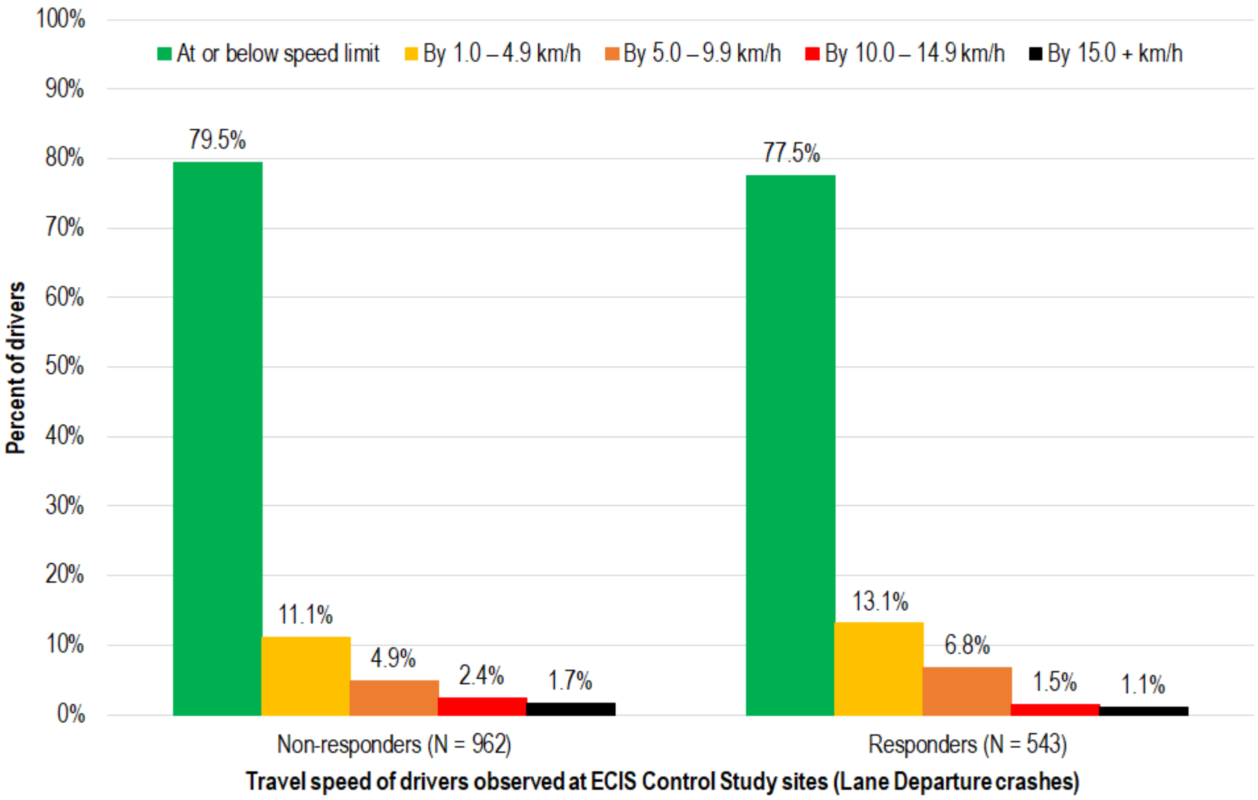

FIGURE B.2 DISTRIBUTION OF MEASURED FREE TRAVEL SPEED AT CRASH LOCATIONS (LANE DEPARTURE CRASHES)

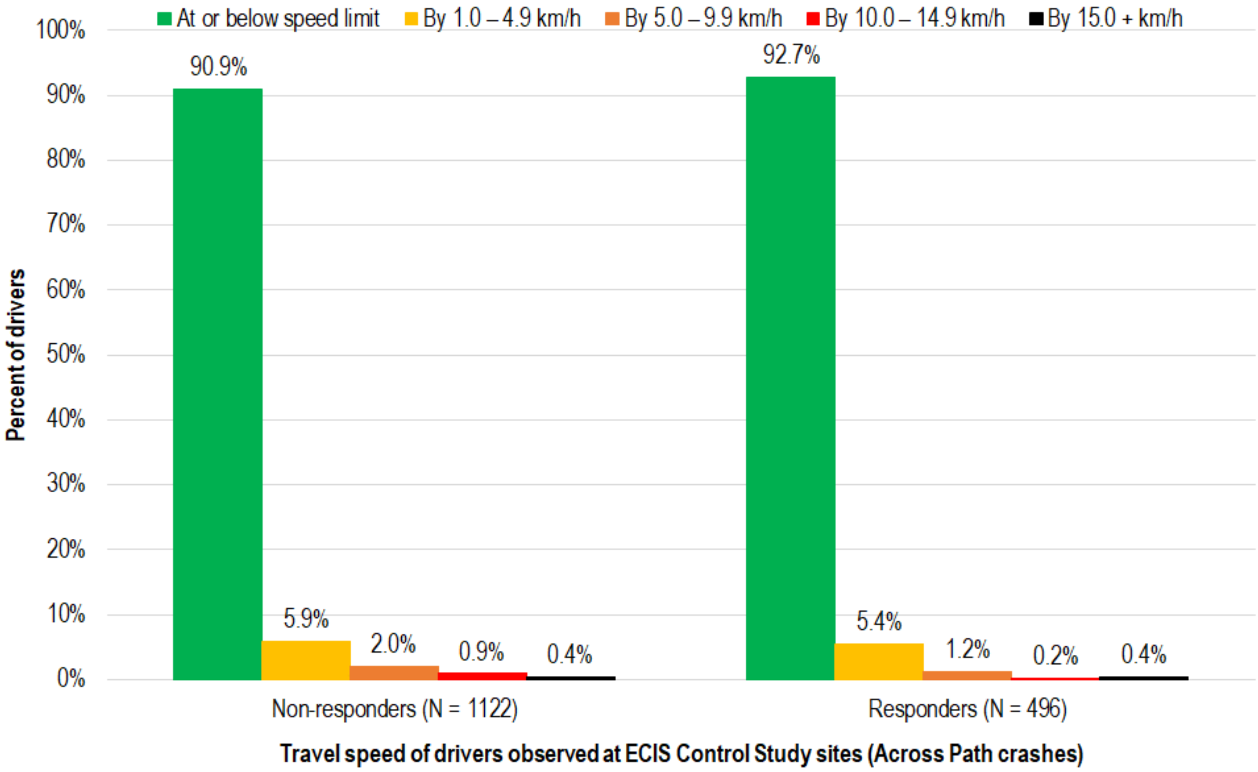

FIGURE B.3 DISTRIBUTION OF MEASURED FREE TRAVEL SPEED AT CRASH LOCATIONS (ACROSS PATH CRASHES)

An important aspect of this analysis is the potential impact of including the travel speeds of non-responders on the reported Case-Control analysis. Here, it must be reinforced that driver age and driver sex was only available for the drivers responding to the survey. Further, Control drivers who self-reported AOD use were excluded from the analysis; this was only possible if responders provided this information. Hence, inclusion of the non-responder travel speed data removes the ability to account for the influence of driver age, driver sex and AOD use by Control drivers, the latter being particularly problematic as the data presented in the Method highlighted that 18 of the 21 AOD positive crash-involved drivers were exceeding the speed limit.

The effect of combining the travel speed data of responders and non-responders was marginal with respect to the percent of drivers exceeding the speed limit. For instance, the proportion of all recorded Control drivers exceeding the speed limit was 14.6% compared to 15.2% of responders only (-0.6%). For drivers associated with Lane Departure crashes, the proportion of all recorded Control drivers exceeding the speed limit was 21.2% compared to 22.5% of responders only (-1.3%), while the respective percent values for drivers associated with Across Path crashes were 8.5% and 7.3% (+1.2%).

Whether inclusion of all recorded Control drivers in the Case-Control analysis acts to amplify (i.e., for the overall and Lane Departure analyses) or attenuate (i.e., for Across Path crashes) the derived relationship between travel speed and crash risk remains to be seen, noting that it is not possible to control for the effects of driver age or sex on crash risk. Further work is being conducted by the ECIS Investigators to explore this point.

In considering this point, it remains important to note that these percent values are not tied to a specific crash or vehicle movement. Rather, these percent values reflect overall speed distribution of recorded control vehicles *irrespective of crash location*. This is important as the matching of Control driver travel speeds to the relevant vehicle in each crash–and hence crash site–is central to the estimation of crash risk. This is especially important as driver speed choice is influenced not only by speed limits, but location specific factors including local road infrastructure, traffic volume and other normative behaviours. It is for this reason that *conditional logistic regression* was used as it explicitly takes advantage of the Case-Control design (see chapter 2 for detail on statistical method).

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APPENDIX C VEHICLE CRASH TESTS AND IMPACT SPEED BOUNDARY CONDITION HEURISTICS

For detail, the reader is referred to *ECIS Report 1*, chapter 7.

TABLE C.1 PERFORMANCE-BASED AUSTRALIAN DESIGN RULES APPLICABLE TO VEHICLES INVOLVED IN ECIS CRASHES[108]

IMPACT TYPE	ADR NUMBER	TEST SPEED (KM/H)	TEST SPECIFICATIONS/OCCUPANTS INCLUDED	EFFECTIVE FROM / VEHICLE TYPES REGULATION APPLIES TO†
Frontal impact: fully distributed crash	69	48.0	Full-width, non-deformable solid concrete barrier ATD: Hybrid III (50th percentile adult male) Positions: driver and front left passenger	1 / 1995 (phased-in to year 2000) MA, MB, MC, NA.
Frontal impact: offset crash	73	56.0 -0/+1	40% overlap (+/- 20 mm), deformable barrier ATD: Hybrid III (50th percentile adult male) Positions: driver and front left passenger	1 / 2000 MA.
Side impact: vehicle-to-vehicle (barrier) crash	72	50.0 +/-1	Perpendicular test using 950 kg (+/- 20 kg) barrier with crushable face (mobile deformable barrier) ATD: EuroSID-1 (50th percentile adult male) Position: driver	1 / 1999 (MB / MC in 2000) MA, MB, MC, NA.
Side impact: pole impact	85	32.0 +/-1	75-degree angle impact with pole ATD: WorldSID 50th percentile adult male Position: driver	11 / 2017 (phased-in: NA in 7 2018) MA, MB, MC, NA.
Rear impact	No regulation			
Rollover	No regulation			

Note†: MA: Passenger car; MB: Forward-control passenger vehicle; MC: Off-road passenger vehicle; NA: Light goods vehicle (up to 4.5 t GVM).

108 ADR 69: https://www.legislation.gov.au/Details/F2012C00138
ADR 73: https://www.legislation.gov.au/Details/F2005L03990
ADR 72: https://www.legislation.gov.au/Details/F2005L03992
ADR 85: https://www.legislation.gov.au/Details/F2015L02109

TABLE C.2 ANCAP CRASH TESTS APPLICABLE TO VEHICLES INVOLVED IN ECIS CRASHES

IMPACT TYPE	VERSION NUMBER	TEST SPEED (KM/H)	TEST SPECIFICATIONS/OCCUPANTS INCLUDED
Frontal impact: fully distributed / width crash	1.1	50.0 +/-1	Full-width, non-deformable solid concrete barrier. ATD (Hybrid III 5th percentile - small female): Adult driver, Adult occupant in rear outboard seat (opposite to driver).
Frontal impact: offset crash	7.1.3	64.0 +/-1	40% overlap (+/- 20 mm), deformable barrier. ATD: 2 adults in front driver and passenger positions (Hybrid III), 10-year-old (Q-10) and 6-year-old child (Q-6) (rear seats).
Side impact: vehicle-to-vehicle (barrier) crash	7.1.4	50.0 +/-1	Perpendicular test using 1300 kg (+/- 20 kg) barrier with crushable face (mobile deformable barrier). ATD: WorldSID 50th percentile (75 kg) male (driver position) plus 10-year-old (Q-10) and 6-year-old child (Q-6) (rear seats) per Child Occupant Protection protocol (v.7.2.1).
Side impact: pole impact	7.0.4	32.0 +/-0.5	75-degree angle impact with pole. ATD: WorldSID 50th percentile (75 kg) male (driver position).
Whiplash protection (for rear-impact crashes)	3.1.2		Dynamic seat-test mounted on sled, with 3 different acceleration levels. ATD: BioRIDIIg rear-crash-dummy. (Note: test protocol for rear occupants, see Whiplash Protection protocol, V.1.0).
Rollover	No test		

Note: Excludes previous pole impact test which was in operation during the lifespan of the vehicles that were being driven at the time of the crash. The Test was applicable only for vehicles with side airbags fitted. For full detail of current ANCAP Technical Protocols, see https://www.ancap.com.au/technical-protocols-and-policies.

TABLE C.3 HEURISTICS FOR THE ASSESSMENT OF IMPACT SPEED (KM/H) AND VEHICLE SAFETY LIMITS (BOUNDARY CONDITIONS) BY ANCAP STAR RATING

IMPACT TYPE	VEHICLE TYPE / COLLISION PARTNER	ANCAP STAR-RATING AND THRESHOLD IMPACT SPEED (KM/H)				
		5	4	3	2	1
Frontal – fully distributed	Passenger car/Fixed object	<65 (either A† or B‡)	<55	<50	<40	<30
Frontal offset	Passenger car/Fixed object	<64 (either A or B)	<50	<40	<30	<30
Frontal narrow offset	Passenger car/Fixed object	<40 (either A or B)	<30	<30	<20	<20
Side oblique / sideswipe, rollover	Passenger car/Fixed object	<50 (B for A; A for B)	<40	<30	<20	<20
Side oblique	4WD/Van	<40 (B for A; A for B)	<30	<20	<20	<20
Side oblique	Truck/Bus	<20 (B for A; A for B)	<10	<10	<10	<10
Side pole / fixed object	SVC	<30	<20	<15	<10	<10
Rear	Speed differential for vehicles: 20 km/h (all vehicles)					

ANCAP rules for vehicles not rated, star-rating based on year of manufacture (based on average): Pre-1990; 1: 1990-1999; 3: 2000-2009; 4: 2010-2013; 5: 2014+
† A: refers to ECIS case vehicle; ‡B: refers to non-case/other vehicle; highest speed used for frontal impacts; bullet vehicle speed used for side impact crashes
Source: Modified from ECIS Safe System-2 Workshop, 2016 (Melbourne) with acknowledgement of Professor Claes Tingvall and Dr Anders Lie.

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APPENDIX D FURTHER DESCRIPTIVE DATA REGARDING THE CASE-CONTROL DATA

D.1 DATA RELATING TO ECIS CRASHES INCLUDED IN THE CASE-CONTROL DATASET

The road location and road class of ECIS crashes included in the Case-Control analysis dataset are presented in Table D.1. In addition, the number of single-vehicle and multiple vehicle crashes are presented.

TABLE D.1 ROAD LOCATION CHARACTERISTICS AND THE NUMBER OF VEHICLES INVOLVED IN CRASHES INCLUDED IN THE CASE-CONTROL ANALYSIS

CHARACTERISTIC	ALL CRASH TYPES (n = 146)	CRASH TYPE	
		LANE DEPARTURE (n = 80)	ACROSS PATH (N = 66)
ROAD GEOMETRY			
Midblock	55.5% (n = 81)	97.5% (n = 78)	4.5% (n = 3)
Intersection	44.5% (n = 65)	2.5% (n = 2)	95.5% (n = 63)
LOCATION			
Urban	56.2% (n = 82)	41.3% (n = 33)	74.2% (n = 49)
Rural	43.8% (n = 64)	58.8% (n = 47)	25.8% (n = 17)
ROAD CLASSIFICATION (HIGHEST CLASSIFICATION WHERE CRASH AT INTERSECTION)			
M	5.4% (n = 8)	4.1% (n = 4)	7.1% (n = 4)
A	8.4% (n = 12)	8.2% (n = 6)	8.6% (n = 6)
B	7.2% (n = 11)	10.3% (n = 9)	2.9% (n = 2)
C	28.1% (n = 39)	33.0% (n = 25)	21.4% (n = 14)
Other Arterial	24.6% (n = 37)	14.4% (n = 11)	38.6% (n = 26)
Local	26.3% (n = 39)	29.9% (n = 25)	21.4% (n = 14)
VEHICLES INVOLVED			
Single vehicle (SVC)	30.8% (n = 45)	56.2% (n = 45)	N/A
Multiple vehicle (MVC)	69.2% (n = 101)	43.8% (n = 35)	100% (n = 66)

The mean age of crash-involved vehicles was 10.5 years (SD = 7.5) and the median vehicle age was 9.0 years (Table D.2). Overall, 24.7% (n = 61) of crash-involved vehicles were manufactured between 2011 – 2016 with an additional 52.2% (n = 129) manufactured between 2001 – 2010. Hence, 76.9% (n = 190) of crash-involved vehicles had been manufactured since 2001. There was no difference in the age distribution of crash-involved vehicles in Lane Departure and Across Path crashes.

TABLE D.2 VEHICLE AGE AND YEAR OF MANUFACTURE OF CRASH-INVOLVED VEHICLES

CHARACTERISTIC	ALL CRASH TYPES A / B VEHICLES (DRIVERS)	CRASH TYPE – CASE A / B VEHICLES	
		LANE DEPARTURE	ACROSS PATH
VEHICLE AGE			
Mean (SD) (years)	10.5 (7.5)	10.7 (7.6)	10.2 (7.5)
Median (years)	9.0	10.0	9.0
Range (years) (year of manufacture)	0 – 42† (2016– 1973)	0 – 42 (2016 – 1973)	0 – 36 (2015 – 1979)
Number of vehicles	247	115	132
YEAR OF MANUFACTURE			
2014–2016	9.7% (n = 24)	8.7% (n = 10)	10.6% (n = 14)
2011–2013	15.0% (n = 37)	13.9% (n = 16)	15.9% (n = 21)
2006–2010	28.7% (n = 71)	27.0% (n = 31)	30.3% (n = 40)
2001–2005	23.5% (n = 58)	26.1% (n = 30)	21.2% (n = 28)
1996–2000	12.6% (n = 31)	14.8% (n = 17)	10.6% (n = 14)
1991–1995	5.3% (n = 13)	4.3% (n = 5)	6.1% (n = 8)
1990 and earlier	5.3% (n = 13)	5.2% (n = 6)	5.3% (n = 7)

^Year of manufacture noting crashes occurred in the period August 2014 to December 2016. Vehicle fleet data presented in footnotes for comparison.[109]

The age distribution of vehicles involved in ECIS crashes was older than the overall Victorian passenger - light commercial vehicle fleet (p = 0.002). Fewer ECIS Case vehicles were manufactured in the period 2014 – 2016 (ECIS: 9.7% cf. Vic: 18.9%) and 2011 – 2013 (ECIS: 15.0% cf. Vic: 17.8%) than the Victorian fleet. A higher proportion of ECIS vehicles were manufactured in the 2006 – 2010 period (ECIS: 28.7% cf. Vic: 25.9%), the 2001 – 2005 period (ECIS: 23.5% cf. Vic: 20.3%), the 1996 – 2000 period (ECIS: 12.6% cf. Vic: 10.4%), the 1991 – 1995 period (ECIS: 5.3% cf. Vic: 3.5%), and prior to 1990 (ECIS: 5.3% cf. Vic: 3.2%) than the Victorian passenger - light commercial vehicle fleet.

109 2016 Registered passenger vehicle / light commercial fleet, Victoria. Australian Bureau of Statistics, Motor Vehicle Census 2019 [microdata].

APPENDIX E FURTHER ALTERNATIVE SCENARIOS

E.1 IMPACT OF SPEED LIMIT CHANGES ON TWO EXEMPLAR INTERSECTION CRASHES

This section presents the outcomes of alternative speed limit scenarios for a crash that occurred at a signalised intersection where both intersecting roads had an 80 km/h speed limit, and a crash where a vehicle turned across the path of an oncoming vehicle that was travelling on a C-class road that had a speed limit of 100 km/h. These two crashes complement the presentation of the alternative speed limit scenarios that were examined for a crash that occurred at an unsignalized intersection where both roads had a 60 km/h speed limit (see Section 6.4.1).

E.1.1 The effect of reducing the speed limit by 10 km/h and 20 km/h on a crash in an 80 km/h speed zone

E.1.1.1 Crash scenario

The crash occurred at a signalised intersection (A road, C road) approximately 45 km south-east of central Melbourne in an urban commercial area. The speed zone was 80 km/h on both roads.

The crash occurred at approximately 2 am in cloudy, overcast, and damp conditions. The crash involved two drivers. The A-vehicle driver held a probationary licence and was driving a late 1990s medium sized 2-star ANCAP rated car; a front-left passenger was also present. The B-vehicle was a young driver in a mid-2000 large 4-star ANCAP rated car. The B-vehicle also had a front-left seat occupant. The B-vehicle driver had an illegal BAC.

The crash occurred after the A-vehicle driver turned right on a green signal. The B-vehicle driver continued into the intersection. The two vehicles collided in the centre of the intersection (Figure E.1).

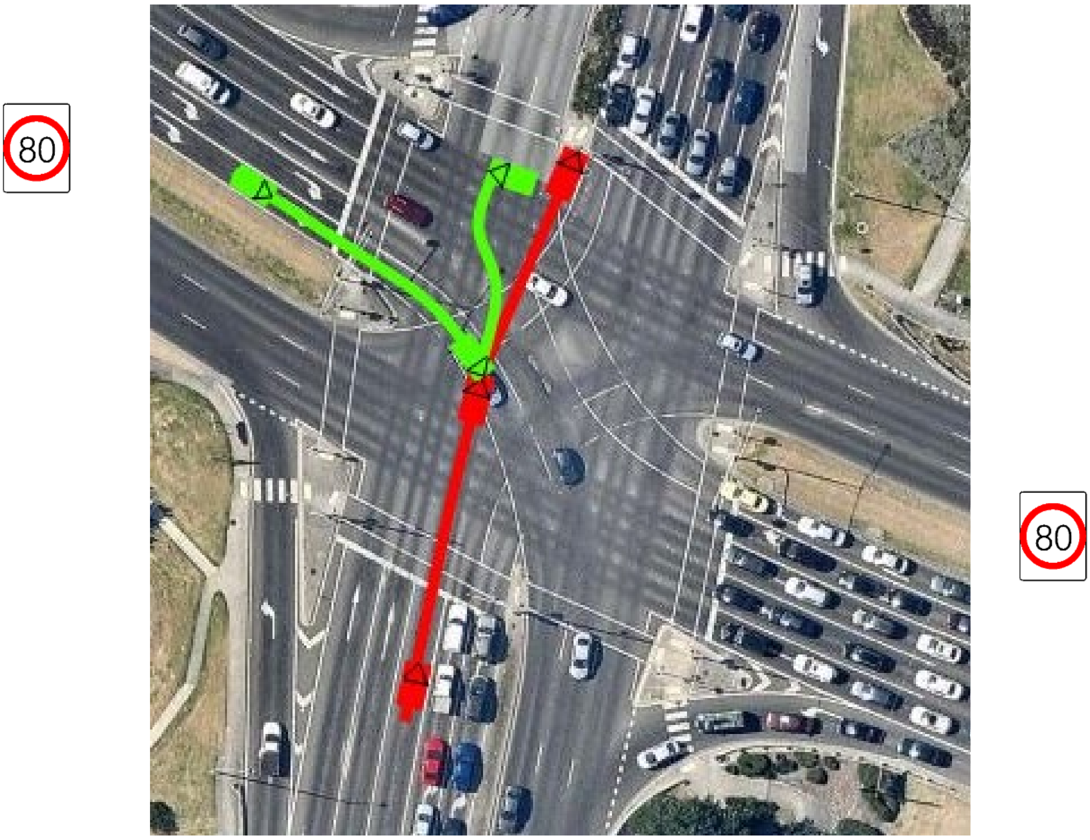

FIGURE E.1 CRASH LOCATION AND VEHICLE MOVEMENTS

Both drivers sustained multiple injuries and were hospitalised with serious injuries (MAIS 3+), as were the passengers of the A-vehicle and the B-vehicle. The A-vehicle driver sustained MAIS 3 lower extremity injuries. The A-vehicle experienced a front right impact with significant crush and intrusion into the occupant compartment. Dual frontal airbags deployed. The B-vehicle also sustained significant frontal damage from the initial impact and the secondary impact with a light pole.

Based on the crash reconstruction, the travel speed estimate for the A-vehicle was 26.8 km/h, having entered the intersection after being stationary. The B-vehicle was estimated to be travelling at 80 km/h, did not brake, and struck the A-vehicle at 78.1 km/h.

E.1.1.2 Interventions

Speed limit reductions were relevant for the speed choice of the B-vehicle driver. The speed reduction measures were:

1. Reduced speed limit from 80 km/h to 70 km/h (- 10 km/h).
2. Reduced speed limit from 80 km/h to 60 km/h (- 20 km/h).

It was assumed that the B-vehicle driver would comply with the speed limit but otherwise not alter their behaviour. It was also assumed that the A-vehicle driver pre-crash behaviour would not change.

E.1.1.3 Crash reconstruction parameters for the intervention scenarios

The A-vehicle and the B-vehicle were matched by make, general model, geometry, and mass. The roadway friction coefficient was set at 0.70 and the concrete kerb friction coefficient was set at 0.80.

The B-vehicle was estimated to be travelling at 80.0 km/h prior to the impact with the speed limit being 80 km/h. The B-vehicle driver was modelled as complying with the lower speed limits. The A-vehicle entered the intersection from a stationary position and was travelling a 26.8 km/h when struck.

E.1.1.4 Crash outcomes

The damage profile of both vehicles in the actual crash scenario were extensive (Table E.1; Figure E.2). In the 80 km/h (original scenario), there was significant frontal damage to both involved vehicles. The B-vehicle also sustained a second impact, striking a light post on the front right of the vehicle.

In the reduced speed limit scenarios, the crash still occurred. As expected, there was a reduction in the crash severity as indexed by the impact velocity, the delta-V and associated force and energy metrics. The vehicle deformation was less but remained significant for both vehicles given the impact velocity (Table E.1; Figure E.2). The maximum crush of the A-vehicle was greater in the 60 km/h speed limit scenario compared to the 70 km/h speed limit alternative scenario due to the difference in the impact point and the shift in the distribution of the damage, noting however the lower Peak Force and the Kinetic Energy values (Figure E.3).

TABLE E.1 CRASH PARAMETERS FOR THE ORIGINAL CRASH AND LOWER SPEED LIMIT SCENARIOS

VEHICLE / SCENARIO	CRASH PARAMETER							
	TRAVEL SPEED (KM/H)	IMPACT SPEED (KM/H)	DELTA-V (KM/H)	IMPACT POINT	PDOF (^{0})	PEAK FORCE (kN)	KINETIC ENERGY (J)	MAXIMUM CRUSH (MM)
A-VEHICLE								
Original crash	**26.8**	**78.1***	**44.3**	**Front, centre right**	**44.3**	**458.7**	**42,491**	**973**
Change in speed limit, main carriageway from 80 km/h								
To 70 km/h	26.8	69.2 [-11.4%]	43.4 [-2.0%]	Front, centre right	38.9	390.5 [-14.9%]	42,365 [-0.3%]	745 [-23.5%]
To 60 km/h	26.8	59.4 [-23.9%]	39.5 [-10.8%]	Front, centre, right	36.9	361.4 [-21.2%]	42,157 [-0.8%]	806 [-17.2%]
B-VEHICLE								
Original crash	**80.0**	**78.1**	**36.5**	**Front, distributed**	**-25.4**	**458.4**	**433,881**	**624**
Change in speed limit, main carriageway from 80 km/h								
To 70 km/h	70.0 [-12.5 %]	69.2 [-11.4%]	35.9 [-1.6%]	Front, centre-left	-23.8	390.2 [-14.9%]	340,906 [-21.4%]	625 [0.2%]
To 60 km/h	60.0 [-25.0%]	59.4 [-23.9%]	33.7 [-7.7%]	Front, centre-left	-28.1	361.1 [-21.2%]	251,418 [-42.1%]	574 [-8.0%]

Note: this is the B-vehicle speed as the 'bullet' vehicle.

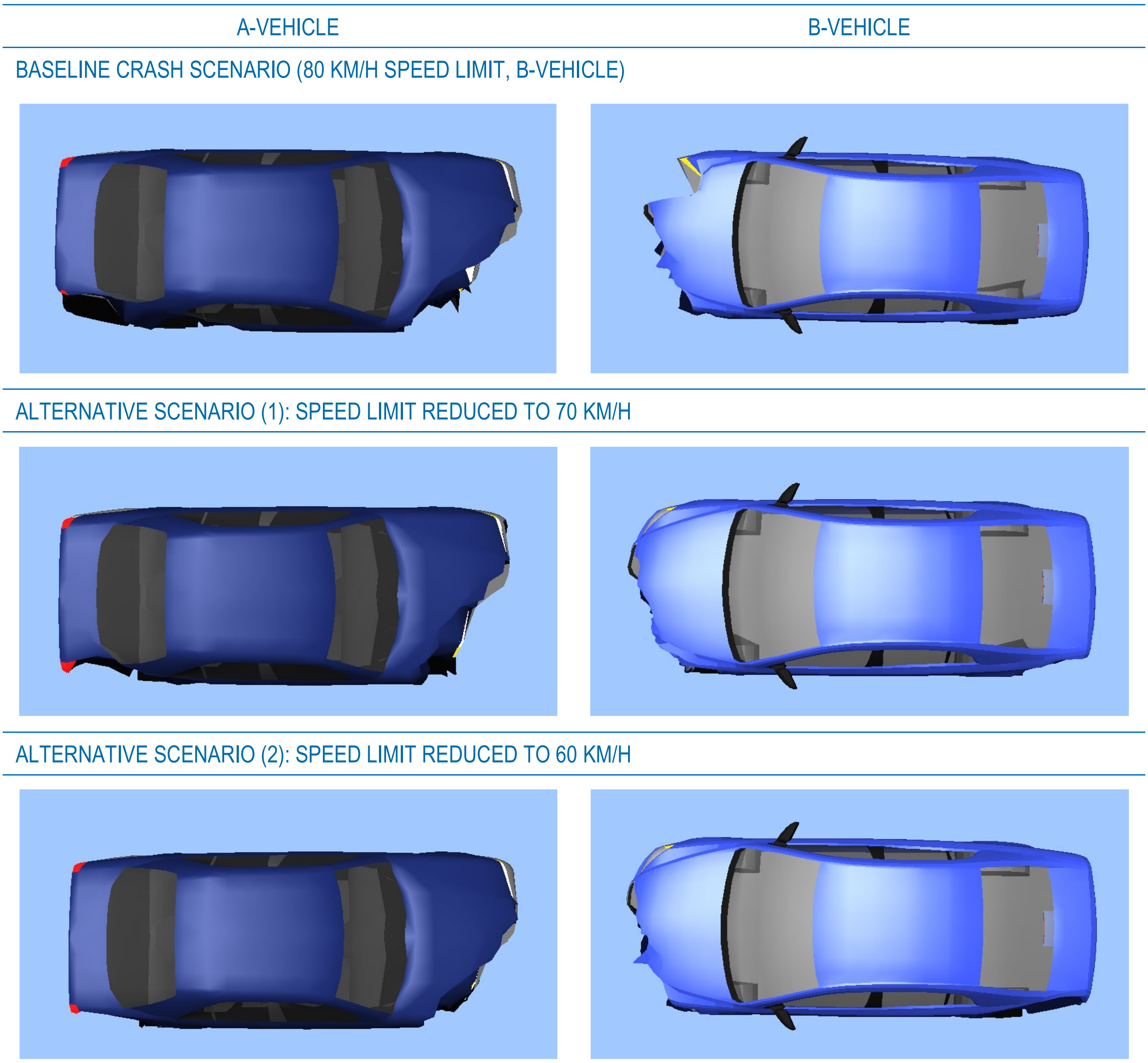

FIGURE E.2 CRASH RECONSTRUCTION REPRESENTATION OF IMPACT DAMAGE

E.1.1.5 Interpretation and summary

In both speed reduction scenarios, the crash would still occur however the point of impact and the PDOF shifted subtly. This, combined with the lower impact speed, changed the dynamics of the impact and with less energy the B-vehicle would not strike the light post as a second impact.

The impact speed reduced from 78.1 km/h to 69.2 km/h and 59.4 km/h in the revised speed limit scenarios (Table E.1). With the A-vehicle having a 2-star safety rating and the B-vehicle having a 4-star safety rating, these impact speeds are above the established impact speed boundary condition where serious injury would be expected to be avoided (Appendix C, see chapter 7 of *ECIS Report 1* for discussion). The impact speeds remain above current regulatory crash test speeds for frontal impact crashes (Appendix C). The crash energy remained high, and the vehicle deformation remained substantial.

The reduction in the speed limit resulted in demonstrable reductions in all crash outcome metrics. Consequently, the risk of serious injury would be lower, however the interaction of the impact speed with the relatively low vehicle safety for the A-vehicle driver still exposes those occupants to the threat of serious injury. Notably, the B-vehicle experienced less deformation, particularly in the 60 km/h speed limit scenario; this translates to a lower risk of serious injury than was seen in the original scenario where the impact speed was 78.1 km/h (see chapter 5, Figure 5.1, injury risk curve).

FIGURE E.3 CHANGE IN MAXIMUM CRUSH, PEAK FORCE, AND IMPACT VELOCITY BY SPEED LIMIT CHANGES FOR THE A-VEHICLE AND THE B-VEHICLE RELATIVE TO THE ACTUAL CRASH SCENARIO

E.1.2 The effect of reducing the speed limit by 10 km/h, 20 km/h and 30 km/h on a crash in a 100 km/h speed zone

E.1.2.1 Crash scenario

The crash occurred at an unsignalized intersection approximately 100 km south-west of central Melbourne and south of Geelong in Victoria.

The crash occurred in the afternoon in clear and dry conditions. The crash involved two drivers. The A-vehicle driver was a middle-aged female driving a late model medium sized 4-star ANCAP rated car. The B-vehicle was a young female driving a late model small 4-star ANCAP rated car.

The crash occurred after the A-vehicle driver entered the main carriageway from a local street (50 km/h speed limit) to execute a right turn. The A-vehicle driver was struck by an oncoming vehicle travelling on the main carriageway (100 km/h speed limit; C-class road) (Figure E.4).

Both drivers sustained multiple injuries and were hospitalised. The A-vehicle driver sustained an MAIS 5 injury (pelvis). The A-vehicle experienced a right-side passenger compartment impact with significant crush and intrusion into the occupant compartment. The B-vehicle sustained frontal damage.

Based on the crash reconstruction, the travel speed estimate for the A-vehicle was 9.7 km/h upon entering the intersection. The A-vehicle was moving at 18.4 km/h when struck. The B-vehicle was estimated to be travelling at 94.0 km/h and braked prior to the impact; the impact speed was 64.1 km/h.

E.1.2.2 Interventions

The alternative scenarios were modelled on the main carriageway (C class road). These changes were relevant for the speed choice of the B-vehicle driver. The speed reduction measures were:

1. Reduced speed limit from 100 km/h to 90 km/h (- 10 km/h).
2. Reduced speed limit from 100 km/h to 80 km/h (- 20 km/h).
3. Reduced speed limit from 100 km/h to 70 km/h (- 30 km/h).

It was assumed that the B-vehicle driver would comply with the speed limit and the A-vehicle driver pre-crash behaviour would not change.

E.1.2.3 Crash reconstruction parameters for the intervention scenarios

The A-vehicle and the B-vehicle were matched by type and mass. The B-vehicle driver was modelled as perceiving the A-vehicle entering the carriageway 2.3 seconds prior (i.e., based on sight distance) and braked 1.1 seconds prior to the collision. The B-vehicle had ABS fitted. The A-vehicle did not brake. The roadway friction coefficient used was 0.75.

The B-vehicle was estimated to be travelling at 94.0 km/h prior to the impact with the speed limit being 100 km/h. The B-vehicle driver was modelled as complying with the lower speed limits. The A-vehicle entered the intersection at 9.7 km/h and accelerated across the intersection before being struck by the B-vehicle.

There were two objectives in modelling these alternative scenarios:

A. To demonstrate and assess the effect of a lower B-vehicle travel speed achieved by speed limit reductions on crash outcomes, holding all else constant. That is, the B-vehicle driver reacts in the same way at a fixed distance away but is travelling at a lower travel speed.

B. To demonstrate and assess the effect of a lower B-vehicle travel speed achieved by speed limit reductions on the crash outcomes, but with modifications made such that the vehicles impact at the same physical location on the road with the point of impact also being the same. This serves to demonstrate the reduction in the impact speed on vehicle damage and crash metrics.

To address Objective A, the B-vehicle driver perceives and brakes at the same physical point on the road as was the case in the actual crash scenario. This means that the distance of the B-vehicle for the A-driver upon approach and entering the intersection was the same. In these alternative scenarios, the only behaviour that was changed by the crash reconstructionist was the travel speed of the B-vehicle driver. As with all alternative scenarios, an assumption was made that the driver would comply with the revised speed limit; this was considered a reasonable assumption as both drivers were compliant with the speed limit in the original crash event. Taking this approach highlights the influence of the lower speed limits on the crash outcomes alone. All other driver behaviours were held fixed, including the brake force application by the B-vehicle driver and the time duration between perception and braking. Findings relating to Objective A are presented in section E.1.2.4.

To demonstrate the effect of a lower travel speed and hence impact speed for a given impact (Objective B), the position of the B-vehicle was adjusted forward by the crash reconstructionist such that the B-vehicle driver perceived and braked when the A-vehicle entered the intersection. Adjusting the proximity of the B-vehicle to the intersection was necessary due to the lower travel speed of the B-vehicle and the speed differential between the A-vehicle and the B-vehicle; that is, the physical distance must initially be less for the vehicles to impact at the same point on the road and impact point on the vehicle. In practical terms this means that the A-vehicle driver would proceed with the manoeuvre despite the opposing vehicle being closer. The intent of this *forced* approach was to demonstrate the differential damage and crash energy metrics associated with lower impact speeds driven by lower speed limits. Hence, these findings highlight the influence of the lower speed limits on crash metrics *given that a crash continues to occur*. Findings relating to Objective B are presented in section E.1.2.5.

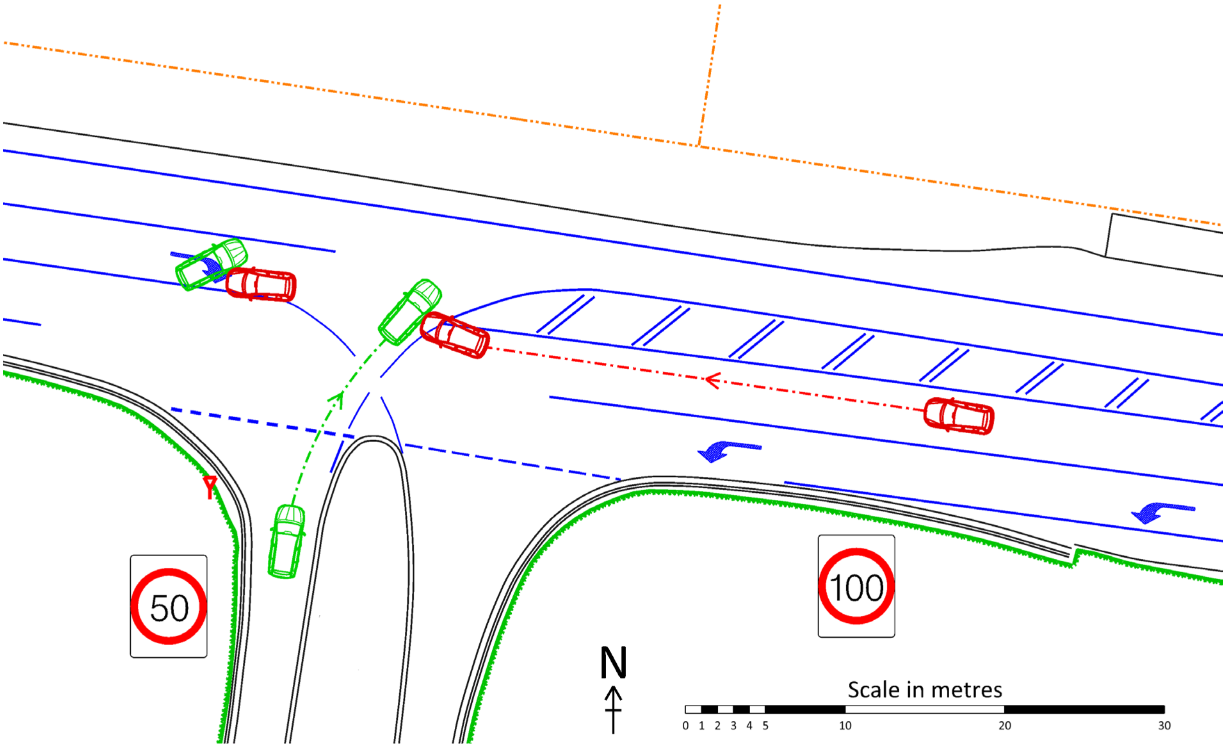

FIGURE E.4 CRASH LOCATION AND VEHICLE MOVEMENTS

E.1.2.4 Objective A (fixed perception and braking): Crash outcomes

E.1.2.4.1 Results

Per the crash described in E.1.2.1 and as shown in Figure E.4), the damage sustained by both vehicles in the actual crash scenario was extensive (Figure E.5). The crash reconstruction estimated 38 cm of crush at its maximum focussed on the right driver door for the A-vehicle and 48.5 cm crush focussed on the right-front of the B-vehicle.

When holding the physical braking point of the B-vehicle on the road the same as per the original scenario, the reduction in travel speed due to braking in the 80 km/h and 70 km/h intervention scenarios was sufficient to bring the B-vehicle to a complete stop prior to striking the A-vehicle. By holding the response of the B-vehicle driver with respect to the point of recognising the emerging A-vehicle and braking constant, the physical distance to the A-vehicle is the same, with the key difference being that the vehicle is travelling at a lower speed as dictated by the speed limit. With the lower travel speed, there is sufficient distance for the vehicle to stop given the braking performance of the vehicle. In this approach, the A-vehicle driver makes the decision to enter the carriageway when the vehicle is physically the same distance away.

Where the speed limit was reduced from 100 km/h to 90 km/h the crash still occurred. Here it is important to note that the B-vehicle was traveling at 94.1 km/h in the original scenario. Thus, the reduction in travel speed of 4.1 km/h was insufficient for the crash to be avoided. As shown in Table E.2, there was a reduction in the crash severity as indexed by the impact velocity, the delta-V and associated force and energy metrics (Figure E.6). The vehicle deformation was less and the impact point shifted to be aft of the original impact point (see Figure E.5).

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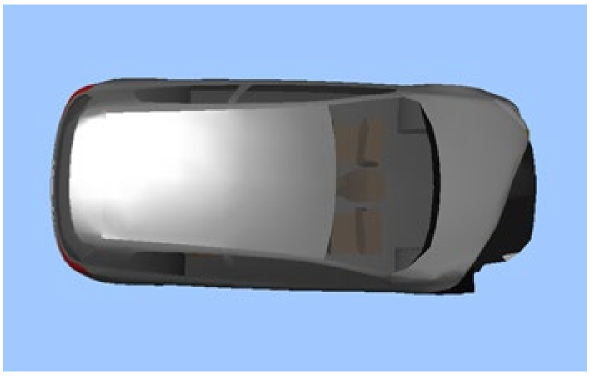
TABLE E.2 CRASH PARAMETERS FOR THE ORIGINAL CRASH AND LOWER SPEED LIMIT SCENARIOS

VEHICLE / SCENARIO	CRASH PARAMETER							
	TRAVEL SPEED (KM/H)	IMPACT SPEED (KM/H)	DELTA-V (KM/H)	IMPACT POINT	PDOF (^{0})	PEAK FORCE (kN)	KINETIC ENERGY (J)	MAXIMUM CRUSH (MM)
A-VEHICLE								
Original crash	9.7	64.1*	32.9	Right door	53.3	306.4	20,620	380
Change in speed limit, main carriageway from 100 km/h								
To 90 km/h	9.7	57.5* [-10.3%]	23.1 [-29.8%]	Aft of B-pillar	53.6	206.4 [-32.6%]	21,986 [+6.6%]	321 [-15.5%]
To 80 km/h	9.7	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided
To 70 km/h	9.7	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided
B-VEHICLE								
Original crash	94.0	64.1	37.4	Front right	-1.4	306.4	236,900	485
Change in speed limit, main carriageway from 100 km/h								
To 90 km/h	90.0	57.5 [-10.3%]	28.8 [-22.9%]	Front right	2.0	206.4 [-32.6%]	187,141 [-40.2%]	447 [-7.8%]
To 80 km/h	80.0	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided
To 70 km/h	70.0	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided

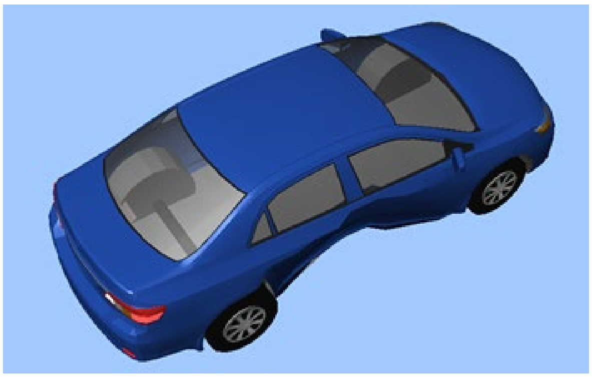
Note: this is the B-vehicle speed as the ‘bullet’ vehicle.

A-VEHICLE B-VEHICLE

BASELINE CRASH SCENARIO (100 KM/H SPEED LIMIT, B-VEHICLE)



ALTERNATIVE SCENARIO (1): SPEED LIMIT REDUCED TO 90 KM/H



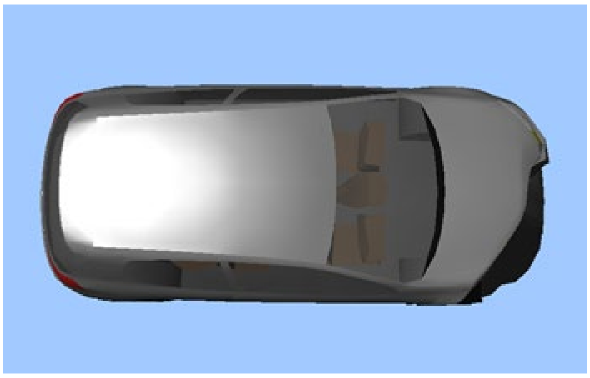


FIGURE E.5 CRASH RECONSTRUCTION REPRESENTATION OF IMPACT DAMAGE

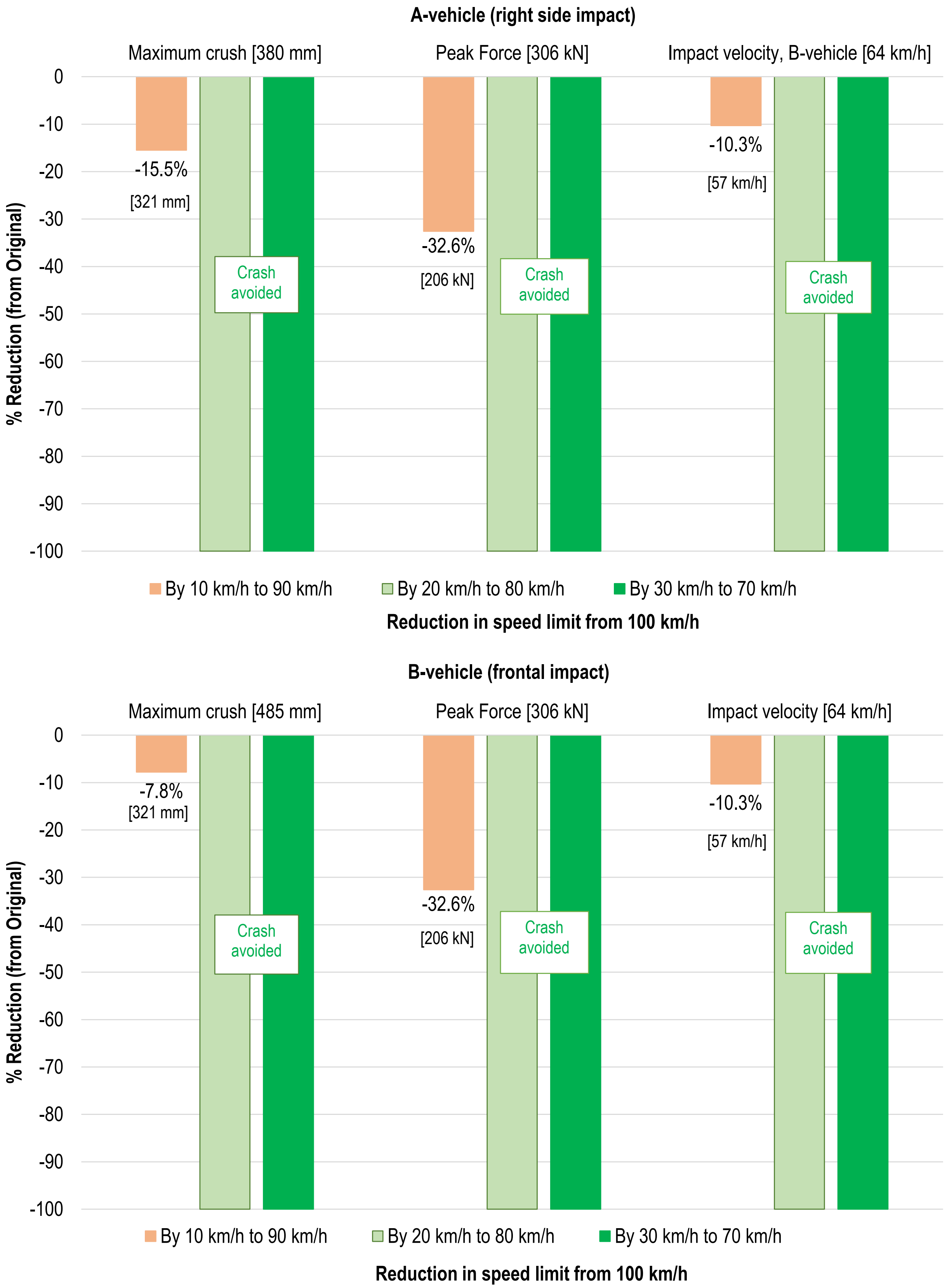


FIGURE E.6 CHANGE IN MAXIMUM CRUSH, PEAK FORCE, AND IMPACT VELOCITY BY SPEED LIMIT CHANGES FOR THE A-VEHICLE AND THE B-VEHICLE RELATIVE TO ACTUAL CRASH SCENARIO

E.1.2.4.2 Interpretation and summary

The reductions in the speed limit resulted in the crash being avoided where the speed limit was reduced from 100 km/h to 80 km/h (-20 km/h). This was also seen when the speed limit was reduced to 70 km/h.

The crash still occurred despite lowering the speed limit to 90 km/h on the main carriageway. The A-vehicle was struck at 57 km/h (10.3% reduction) and consequently the Peak Force was lower (-32.6%) as was the maximum crush experienced by the B-vehicle (-7.8%). While in percent terms these reductions appear substantial, the injury severity of the A-vehicle driver is unlikely to be substantially different in this side impact configuration. Based on the impact speed, the probability of the A-vehicle driver sustaining an MAIS 3+ injury remains high (see chapter 5). It is notable that the impact occurred above the current side impact crash test speed of 50 km/h and above the impact speed boundary for a 4-star ANCAP vehicle (see *ECIS Report 1*, chapter 7; Appendix C, this report). For the B-vehicle driver, the impact speed was reduced by 7 km/h to be 57 km/h. Given the injury profile of this driver (MAIS 1), little change in the injury severity would be expected.

The findings assume fixed behaviour in that the B-vehicle driver perceived the A-vehicle from the same distance from the intersection, had the same reaction time and braked in the same way as the actual crash scenario. Reductions in travel speed were applicable only to the B-vehicle.

In short, a reduction in the speed limit from 100 km/h to 80 km/h (and lower) would result in the crash being avoided entirely. The reduction to 90 km/h would be insufficient to materially reduce the likelihood of the A-vehicle driver sustaining an MAIS 3+ injury.

E.1.2.5 Objective B (fixed impact to vehicle): Crash outcomes

E.1.2.5.1 Results

As discussed above, in the observed crash the impact of the B-vehicle with the right passenger door of the A-vehicle at 64.1 km/h resulted in substantial crush (380 mm). This is consistent with a high energy impact and was reflected in the MAIS 5 pelvis injury sustained by the A-vehicle driver. The damage to the front right of the B-vehicle was also significant (maximum crush: 485 mm) with the driver also hospitalised.

The speed limit reduction alternative scenarios were implemented in such a way as to emulate the same impact, including the impact point on both vehicles. This was done to demonstrate the change in impact speed that is achieved by lower speed limits, reductions across energy-based metrics (i.e., delta-V, peak force, kinetic energy) and the consequent reduction in the maximum crush values for both crash-involved vehicles (Table E.3, Figure E.7, Figure E.8).

While the reduction in the speed limit from 100 km/h to 90 km/h for the B-vehicle translated to a lower impact speed (59.7 km/h) and therefore reductions in delta-V, peak force, kinetic energy and maximum crush, the reductions were less than 10% of their original values for the A-vehicle. The impact speed at which the A-vehicle was struck (59.7 km/h) was higher than the vehicle-based side impact crash test speed (50.0 km/h, Appendix C).

The reduction of the speed limit to 80 km/h for the B-vehicle resulted in the impact speed with the A-vehicle being 50.8 km/h. In turn, the degree of crush sustained by both vehicles was lower as were the key crash energy metrics. While the impact speed for the B-vehicle driver (4-star safety) brought the frontal impact to be at the upper margin of the vehicle boundary condition (Table C.3, Appendix), the impact remained above the boundary condition impact speed for a side impact for the A-vehicle (4-star); this is reflected in the damage profile that can be seen in Figure E.7. As a consequence, the A-vehicle driver remains at risk of serious injury, and hence, the speed limit reduction to 80 km/h is insufficient for this intersection scenario.

By reducing the speed limit to 70 km/h, the impact speed reduced to 41.6 km/h for the A-vehicle; this was the estimated speed when the B-vehicle strikes the A-vehicle driver door. As a consequence of this lower impact speed, all crash energy metrics were markedly lower for both the A-vehicle and the B-vehicle. This was reflected in the degree of crush observed in the A-vehicle (27.4 cm) localised at the driver door and in the B-vehicle (36.5 cm) that was localised on the front-right of the vehicle. The reduction in energy values from the original crash was large, both in absolute terms and in percentage terms (Table E.3).

TABLE E.3 CRASH PARAMETERS FOR THE ORIGINAL CRASH AND LOWER SPEED LIMIT SCENARIOS

VEHICLE / SCENARIO	CRASH PARAMETER							
	TRAVEL SPEED (KM/H)	IMPACT SPEED (KM/H)	DELTA-V (KM/H)	IMPACT POINT	PDOF (0)	PEAK FORCE (kN)	KINETIC ENERGY (J)	MAXIMUM CRUSH (MM)
A-VEHICLE								
Original crash	9.7	64.1*	32.9	Right door	53.3	306.4	20,620	380
Change in speed limit, main carriageway from 100 km/h								
To 90 km/h	9.7	59.7* [-6.9%]	30.2 [-8.2%]	Right door	53.2	276.5 [-9.7%]	19,994 [-3.0%]	359 [-5.5%]
To 80 km/h	9.7	50.8* [-21.8%]	25.6 [-22.2%]	Right door	53.5	224.8 [-26.6%]	20,434 [-0.9%]	324 [-14.7%]
To 70 km/h	9.7	41.6* [-35.1%]	20.9 [-36.5%]	Right door	53.1	179.8 [-41.3%]	19,879 [-3.6%]	274 [-27.9%]
B-VEHICLE								
Original crash	94.0	64.1	37.4	Front right	-1.4	306.4	236,900	485
Change in speed limit, main carriageway from 100 km/h								
To 90 km/h	90.0	59.7 [-6.9%]	35.0 [-6.4%]	Front right	-0.7	276.5 [-9.7%]	200,269 [-15.5%]	469 [-3.3%]
To 80 km/h	80.0	50.8 [-21.8%]	30.6 [-18.2%]	Front right	-0.5	224.8 [-26.6%]	147,550 [-37.5%]	419 [-13.6%]
To 70 km/h	70.0	41.6 [-35.1%]	26.1 [-30.2%]	Front right	-1.0	179.8 [-41.3%]	94,389 [-60.2%]	365 [-24.7%]

Note: this is the B-vehicle speed as the 'bullet' vehicle.

E.1.2.5.2 Interpretation and summary

The conduct of the speed limit reduction alternative scenarios demonstrates the severe risk associated with high-speed side impact crashes and the need to ensure speed limits are set appropriately. For this type of crash, and where the vehicles involved both held a 4-star ANCAP safety rating, reducing the speed limit to 70 km/h was necessary to bring the impact speed within the safety envelope of the vehicle where the driver could expect a degree of protection against serious injury, although the risk whilst attenuated remains. Had the A-vehicle held a 5-star ANCAP rating, the reduction of the speed limit to 80 km/h would barely bring the crash to be within the safety envelope of the vehicle. Following this point, the tolerable impact speed in a side impact crash is modified by the type of opposing vehicle such that larger vehicles require a lower impact speed, as do lower safety rated passenger vehicles in vehicle-to-vehicle impacts.

This case study highlights the need for a combined approach when addressing the harm associated with side impact crashes that are characteristic of Across Path intersection crashes. While improved side impact vehicle technology plays a key role, in the absence of complete separation of vehicles, reduction of the speed limit becomes the primary safety intervention. The findings here however demonstrate that a reduction of the speed limit to 80 km/h is insufficient in the context of the Victorian vehicle fleet, and that a speed limit of 70 km/h at intersections is required for the protection of vehicle occupants and for reductions in serious injuries associated with this crash type to be achieved.

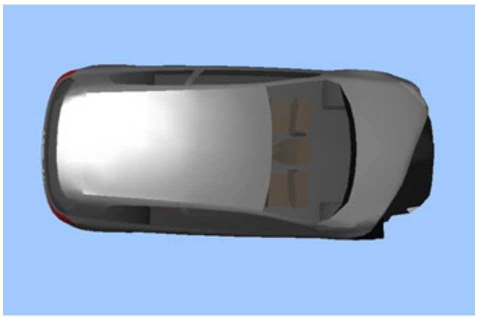
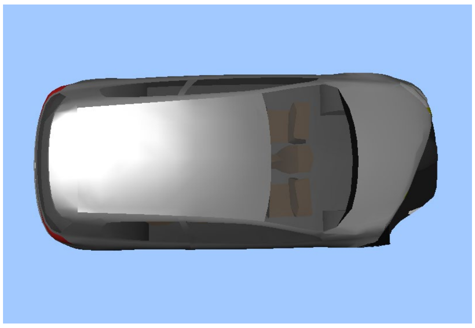
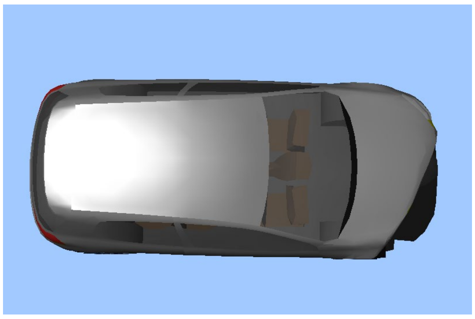
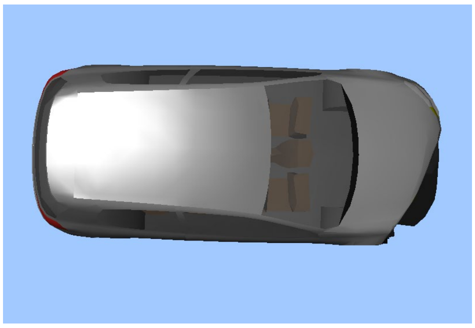
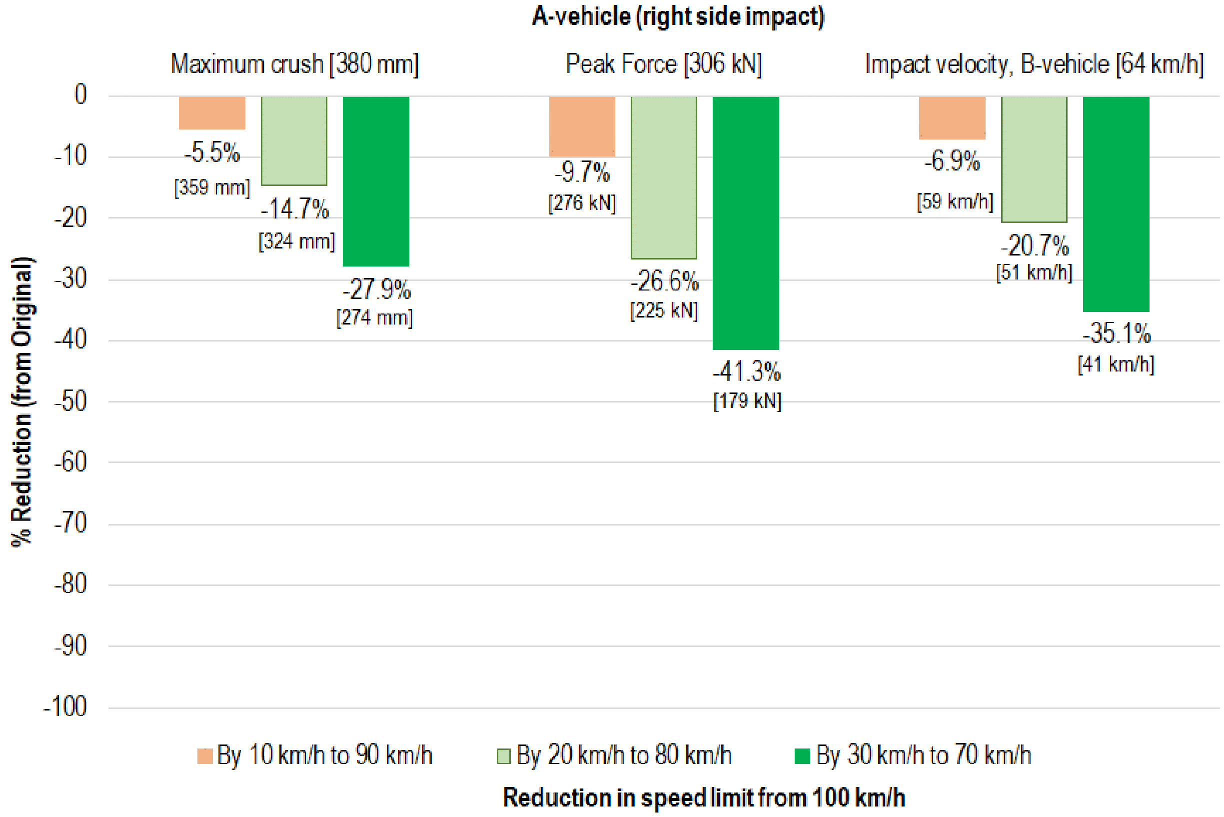
A-VEHICLE	B-VEHICLE
BASELINE CRASH SCENARIO (100 KM/H SPEED LIMIT, B-VEHICLE)	
	
ALTERNATIVE SCENARIO (1): SPEED LIMIT REDUCED TO 90 KM/H	
	
ALTERNATIVE SCENARIO (2): SPEED LIMIT REDUCED TO 80 KM/H	
	
ALTERNATIVE SCENARIO (3): SPEED LIMIT REDUCED TO 70 KM/H	
	

FIGURE E.7 CRASH RECONSTRUCTION REPRESENTATION OF IMPACT DAMAGE



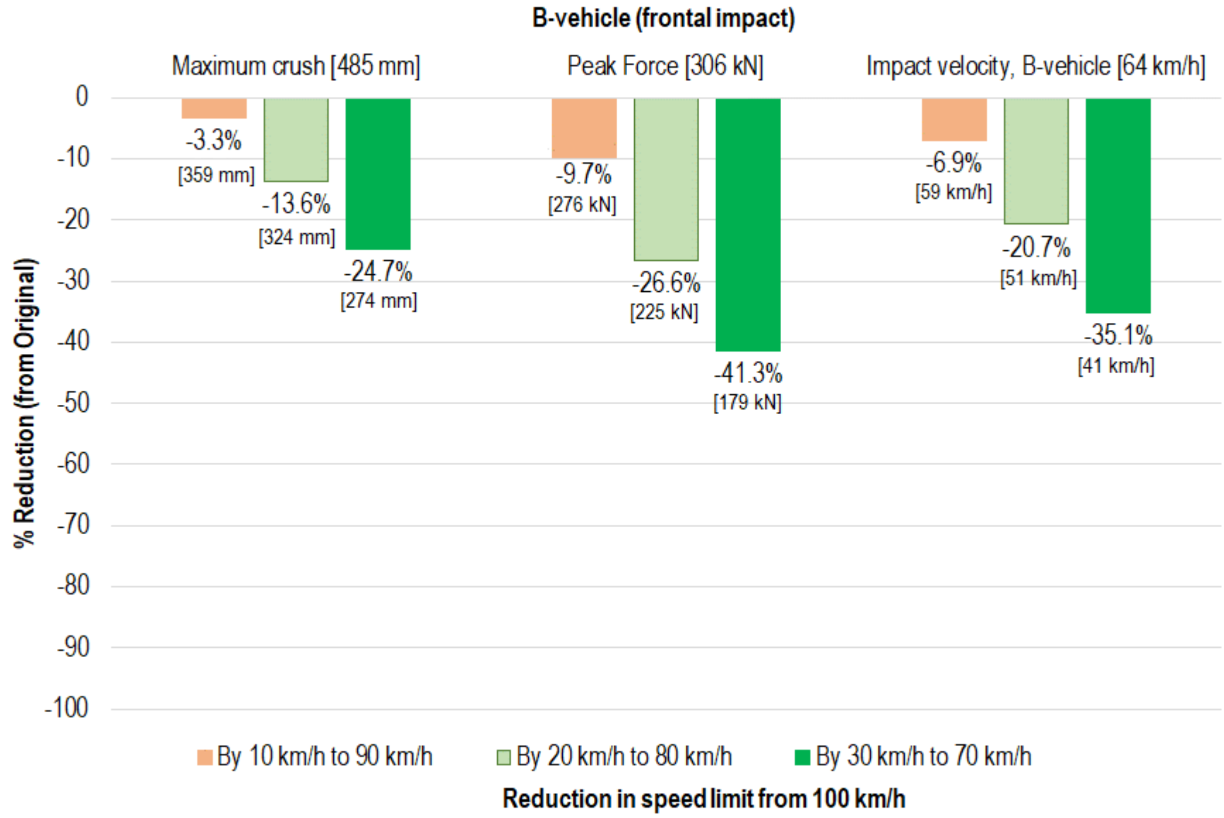


FIGURE E.8 CHANGE IN MAXIMUM CRUSH, PEAK FORCE, AND IMPACT VELOCITY BY SPEED LIMIT CHANGES FOR THE A-VEHICLE AND THE B-VEHICLE RELATIVE TO ACTUAL CRASH SCENARIO

E.2 IMPACT OF SPEED LIMIT CHANGES ON TWO EXEMPLAR SINGLE-VEHICLE RUN-OFF-ROAD CRASHES

This section presents the outcomes of alternative speed limit scenarios for two single-vehicle run-off-road crashes, one of which occurred in a 60 km/h speed zone and one that occurred in an 80 km/h speed zone. These two crashes complement the alternative scenario analysis of a single-vehicle run-off-road crash that occurred in a 100 km/h speed zone presented in Section 6.4.2.

E.2.1 The effect of reducing the speed limit by 10 km/h and 20 km/h on a crash in a 60 km/h speed zone

E.2.1.1 Crash scenario

The crash occurred on a 60 km/h local road. The crash location was approximately 150 km north-west of central Melbourne in a rural residential area. The road had no line markings, had an unsealed shoulder and grass verge immediately abutting the road on the right side. There was a wider unsealed gravel shoulder on the left.

The crash occurred in the early morning (dawn) in clear and dry conditions. The single-vehicle crash occurred after the A-vehicle driver lost control when over-correcting having drifted to the right side of the road (Figure E.9). The driver steered, released the accelerator pedal, and applied the brakes; the vehicle then began to yaw. The vehicle struck a tree that was 43 cm diameter and was 4.7 metres off the side of the road.

The young female driver was driving a circa-2000 small car (ANCAP 3-star). The crash configuration was a side impact on the driver side, centred at the B-pillar. The vehicle was fitted with a front driver airbag which did not deploy (as expected). The driver sustained multiple MAIS 3+ chest injuries, multiple MAIS 2 injuries of the vertebral column and pelvis, as well as multiple lacerations to the head and other bruises.

Based on the crash reconstruction, the travel speed estimate for the vehicle was 60.3 km/h, and the vehicle was estimated to be travelling at 60.2 km/h at the point of leaving the sealed carriageway. The impact speed was 28.1 km/h.

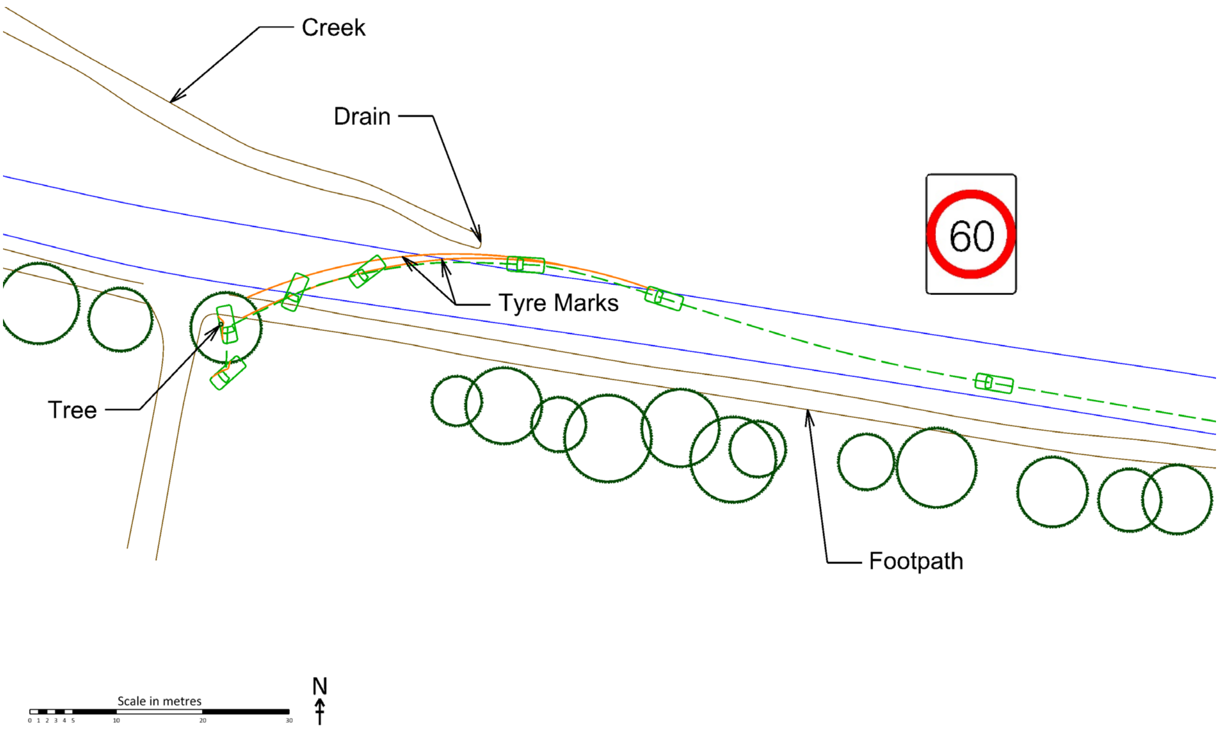


FIGURE E.9 CRASH LOCATION AND VEHICLE MOVEMENTS

E.2.1.2 Interventions

Two speed reduction scenarios were modelled with the driver complying with the revised speed limits:

1. Reduced speed limit from 60 km/h to 50 km/h (- 10 km/h).
2. Reduced speed limit from 60 km/h to 40 km/h (- 20 km/h).

It was also assumed the driver would not alter their pre-crash behaviours.

E.2.1.3 Crash reconstruction parameters for the intervention scenarios

The vehicle used in the simulation was matched by type and mass. The steering and braking actions of the driver were modelled. The friction coefficient for the roadway was 0.80 and 0.60 for the shoulder.

E.2.1.4 Crash outcomes

The impact of 28.1 km/h resulted in significant crush and loss of compartment space for the driver (Table E.3, Figure E.10). There was significant loading of the right-side B-pillar which resulted in significant crush. With loading of the right side of the driver's body, the injuries represent a classic pattern for a pole/tree side impact crash where no airbags were fitted, noting the 3-star ANCAP safety rating of the vehicle.

In the scenario where the speed limit was 50 km/h, the vehicle followed the same trajectory, however the impact was to the front left of the vehicle, having rotated anti-clockwise as per the original scenario. That the impact speed was essentially the same as in the actual crash scenario is a result of the differential loss of speed due to a combination of the complex vehicle dynamics (i.e., yaw, rotation), the mass of the vehicle, and the surface friction coefficients.

In the 40 km/h speed limit scenario, the vehicle trajectory is the same, including the anti-clockwise rotation however the vehicle stops partially on the road edge and partially on the shoulder. The vehicle did not strike the tree or experience any other impact.

TABLE E.3 CRASH PARAMETERS FOR THE ORIGINAL CRASH AND LOWER SPEED LIMIT SCENARIOS

VEHICLE / SCENARIO	CRASH PARAMETER							
	TRAVEL SPEED (KM/H)	IMPACT SPEED (KM/H)	DELTA-V (KM/H)	IMPACT POINT	PDOF (^{0})	PEAK FORCE (kN)	KINETIC ENERGY (J)	MAXIMUM CRUSH (MM)
A-VEHICLE								
Original crash	**60.3**	**28.1**	**32.4**	**Right (driver) side**	**83.4**	**142.8**	**37,401**	**353**
Change in speed limit, main carriageway from 60 km/h								
To 50 km/h	50.4 [-16.4%]	28.0	23.8 [-26.5%]	Frontal, left centre	4.4	85.1 [-40.4%]	38,144 [+2.0%]	505 [+43.1%]
To 40 km/h	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided

BASELINE CRASH SCENARIO (60 KM/H SPEED LIMIT) | ALTERNATIVE SCENARIO (2): SPEED LIMIT OF 50 KM/H

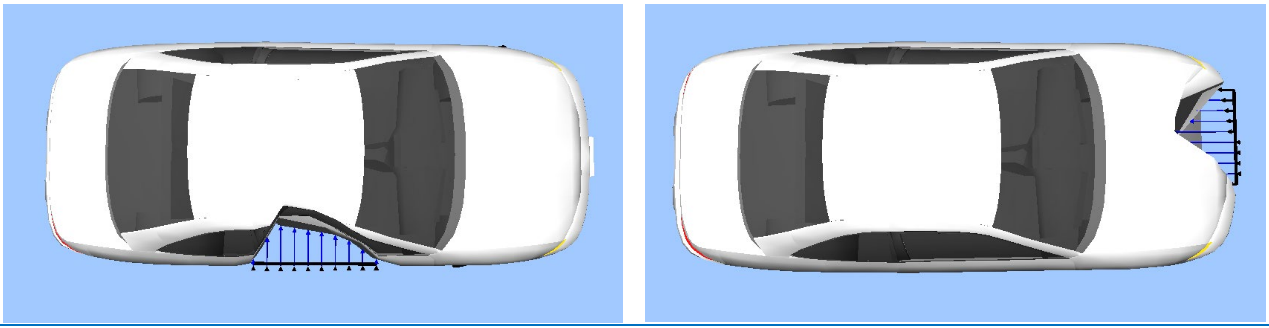


FIGURE E.10 CRASH RECONSTRUCTION REPRESENTATION OF IMPACT DAMAGE

E.2.1.5 Interpretation and summary

This crash highlights the significant impact of what might be considered a benign impact given the impact speed. However, the direct loading of the driver side door was significant. The crash highlights that even when travelling at 60 km/h the level of protection for the driver in the event of a side impact with a tree—even if positioned 4.7 metres from the roadside—is low. It is worth noting that the pole side impact regulation (ADR 85, Appendix C) is designed to improve the safety performance of vehicles specifically for this crash scenario; in this test the impact speed is 32 km/h. It is recognised the vehicles compliant with ADR 85 would have advanced side impact protection systems, including head and thorax side impact airbags.

The energy of the crash was 2% higher in the 50 km/h speed limit scenario; however, this resulted in a frontal impact which is considered to be a more favourable impact compared to a driver side impact. The injury outcome would be substantially better with significantly fewer and lower severity injuries being likely, particularly as the vehicle was fitted with a frontal driver airbag and the impact point on the vehicle. The crash was avoided in the 40 km/h speed limit scenario.

E.2.2 The effect of reducing the speed limit by 10 km/h and 20 km/h on a crash in an 80 km/h speed zone

E.2.2.1 Crash scenario

The crash occurred on a multi-lane arterial highway approximately 40 km east of central Melbourne. The speed limit on the road was 80 km/h. The surrounding environment was urban residential.

The Case Vehicle was travelling south. In overtaking a large commercial vehicle on the right, the Case Vehicle struck the median kerb. This resulted in a loss of control. The vehicle proceeded onto the median (grass), struck a tree (impact 1, 5 cm diameter, 1.9 m from the outer edge of the lane) then had a second full frontal impact with another tree (80 cm diameter, 2.2 metres from the outer edge of the lane). After the second impact the vehicle rolled two one-quarter turns before coming to rest on the roof. The driver applied the brakes after the first impact (see Figure E.11).

The crash occurred at midday in clear and dry conditions. The A-vehicle driver was an upper middle-aged female driving a late-2000 model small 4-star ANCAP rated car. The driver sustained an MAIS 3+ injury of the cervical vertebral column, a number of lacerations to the upper and lower extremities, and extensive bruising.

Based on the crash reconstruction, the travel speed estimate for the A-vehicle was 73.9 km/h. The driver experienced multiple impacts, as shown in Table E.4.

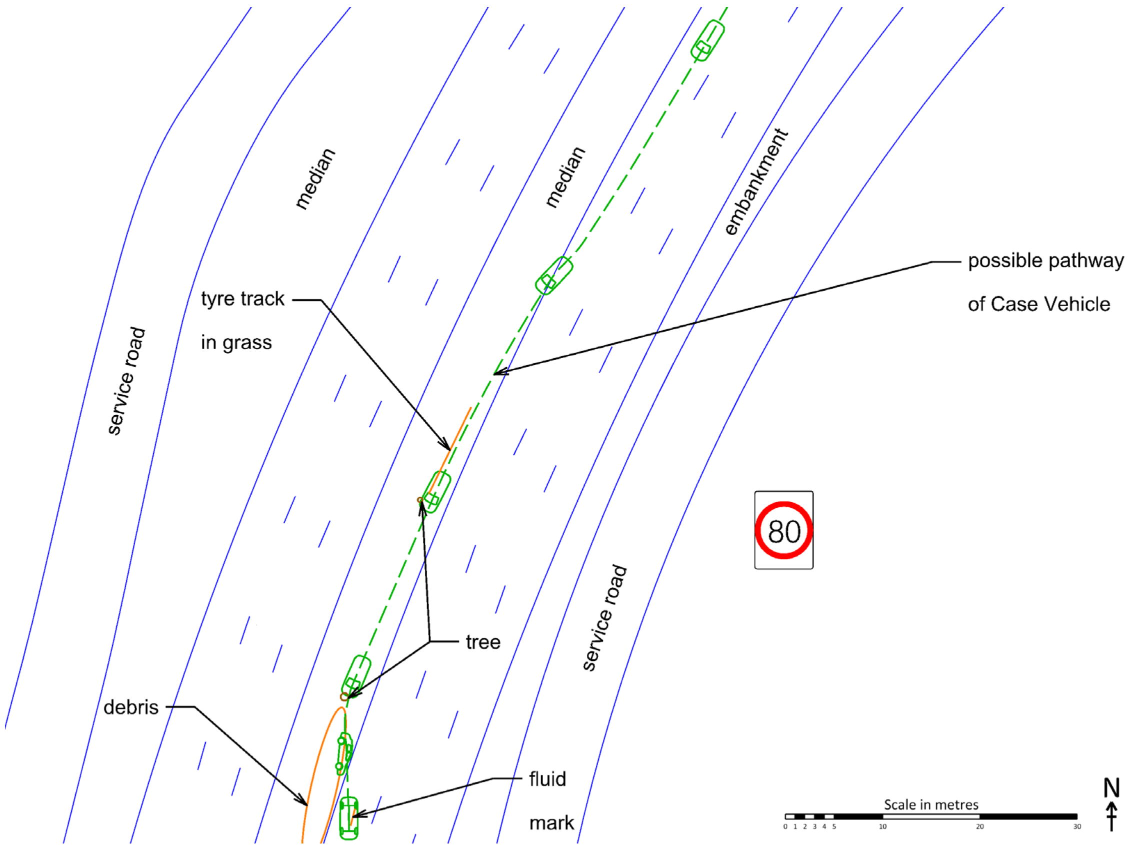


FIGURE E.11 CRASH LOCATION AND VEHICLE MOVEMENTS

E.2.2.2 Interventions

Two speed reduction scenarios were modelled with the driver complying with the revised speed limits:

1. Reduced speed limit from 80 km/h to 70 km/h (- 10 km/h).
2. Reduced speed limit from 80 km/h to 60 km/h (- 20 km/h).

It was also assumed the driver would not alter their pre-crash behaviours.

E.2.2.3 Crash reconstruction parameters for the intervention scenarios

The A-vehicle was matched on make and model. The friction coefficient for the road was set at 0.82 and 0.70 was used for the grass median.

E.2.2.4 Crash outcomes

The original scenario involved three impacts. The first tree impact was relatively benign; however, the second full frontal impact was significant and involved extensive crush to the front of the vehicle (Figure E.12). The dual frontal airbags deployed in this crash. The rollover caused significant roof crush directly above the driver's head. This is the mechanism for the MAIS 3+ cervical column-spinal injury.

In alternative scenario one, the speed limit was reduced to 70 km/h. An assumption was that the driver would comply with the speed limit. The impact speed was 69.7 km/h, only marginally lower than the estimated travel speed in the original scenario. The reduction was sufficient to alter the energy and dynamics of the crash such that the rollover (impact 3) did not occur. Of note was that the energy and crush associated with the first impact increased, however the much more significant second impact (i.e., frontal, tree) was significantly lower. The reductions associated with the re-set speed limit of 60 km/h, assuming a 60.4 km/h travel speed were even more significant.

TABLE E.4 CRASH PARAMETERS FOR THE ORIGINAL CRASH AND LOWER SPEED LIMIT SCENARIOS

VEHICLE / SCENARIO	CRASH PARAMETER							
	TRAVEL SPEED (KM/H)	IMPACT SPEED (KM/H)	DELTA-V (KM/H)	IMPACT POINT	PDOF (⁰)	PEAK FORCE (kN)	KINETIC ENERGY (J)	MAXIMUM CRUSH (MM)
A-VEHICLE								
Original crash	**73.9**	**73.2 (1)** **60.2 (2)** **-**	**3.1** **49.4** **-**	**Front, swipe** **Front centre** **Roll / roof**	**51.9** **-12.1** **-**	**30.9** **390.2** **60.0**	**289,962** **187,578** **7,185**	**32** **2508** **608**
Change in speed limit from 80 km/h								
To 70 km/h	70.4	69.7 (1) *[-4.8%]* 52.5 (2) *[-12.8%]* N/A (3)	4.8 *[+54.8%]* 51.0 *[+3.2%]* N/A	Front right Front centre N/A	54.2 2.0 N/A	66.6 *[+115.5%]* 279.9 *[-28.3%]* N/A	264,076 *[-8.9%]* 145,684 *[-22.3%]* N/A	51.0 *[+59.4%]* 1308 *[-47.5%]* N/A
To 60 km/h	60.4	58.4 (1) *[-20.2%]* 15.8 (2) *[-126.2%]* N/A (3)	8.7 *[+180.6%]* 19.7 *[-60.1%]* N/A	Front left (1) Left side (2) N/A	26.5 -41.4 N/A	57.7 *[+86.1%]* 66.2 *[-83.0%]* N/A	184,068 *[-36.5%]* 14,384 *[-92.3%]* N/A	150 *[+368.8%]* 59.2 [-97.6%] N/A

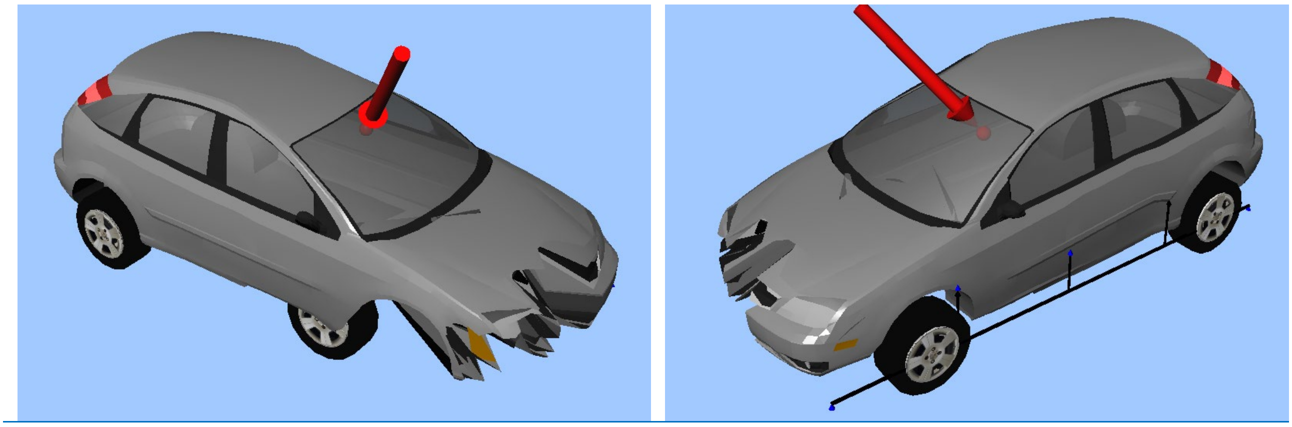
Note: Impact (1) – tree; Impact (2) – tree; Impact (3) - rollover

E.2.2.5 Interpretation and summary

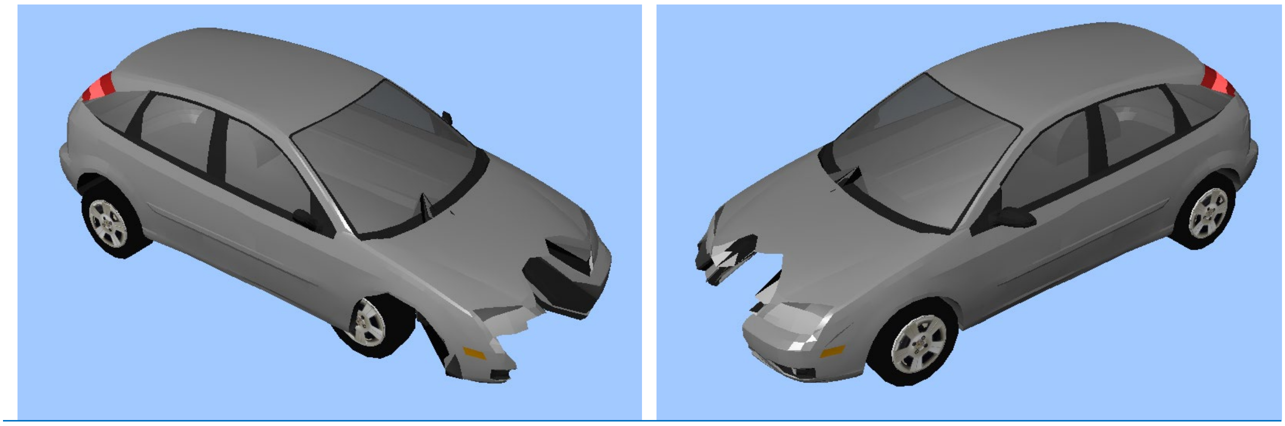
The reduction in travel speed from 73.9 km/h to 70.4 km/h, driven by compliance with a 70 km/h speed limit had a profound effect on this crash. The reduction in the energy of the crash and its influence on vehicle trajectories and subsequent impacts with the two trees in the median translated to the rollover event being eliminated. The importance of this cannot be overstated. The rollover was a direct cause of the MAIS 3+ cervical column injury, as per physical trace evidence on the internal roof lining where the roof crush occurred.

The tree impacts, especially impact 1 in the 70 km/h speed limit alternative scenario remains an injury risk given the impact speed of 69.7 km/h; however, the impact was more of a sideswipe with little force and small deformation. The second impact was more significant (52.5 km/h) but was less than the original scenario; the reduction was even greater in the 60 km/h speed limit scenario. With the vehicle having dual front airbags and a 4-star safety rating, the reduction in the speed limit would result in the driver sustaining less severe injuries and likely no greater than MAIS 1 given the primary injury was that of the cervical spine associated with the rollover that no longer occurs. The result of the speed limit reduction is a significantly more favourable injury outcome for the driver.

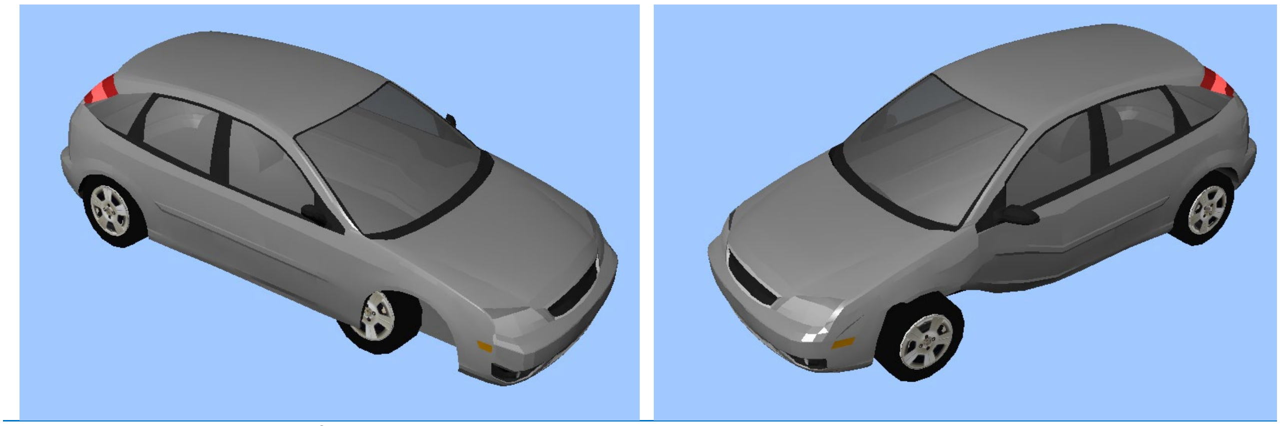
BASELINE CRASH SCENARIO (80 KM/H SPEED LIMIT)



ALTERNATIVE SCENARIO (1): SPEED LIMIT OF 70 KM/H



ALTERNATIVE SCENARIO (2): SPEED LIMIT OF 60 KM/H



Note: The red arrow is the indicative PDOF.

FIGURE E.12 CRASH RECONSTRUCTION REPRESENTATION OF IMPACT DAMAGE

E.3 IMPACT OF SPEED LIMIT CHANGES ON TWO EXEMPLAR HEAD-ON CRASHES

This section presents the outcomes of alternative speed limit scenarios for two head-on crashes, one of which occurred in a 60 km/h speed zone and one that occurred in an 80 km/h speed zone. These two crashes complement the alternative scenario analysis of a head-on crash that occurred in a 100 km/h speed zone presented in Section 6.4.3.

E.3.1 The effect of reducing the speed limit by 10 km/h and 20 km/h on a crash in a 60 km/h speed zone

E.3.1.1 Crash scenario

The crash occurred on a 60 km/h C-class road set on a bridge approximately 85 km south-west of central Melbourne. Opposing traffic was separated by a single solid white line. The surrounding environment was urban parkland.

The crash occurred in the late afternoon in clear and dry conditions. The crash involved two drivers. The A-vehicle driver was a young female driving a late-2000 model year small 3-star ANCAP rated car. The B-vehicle was a middle-aged male driving an early- 2000 large passenger-car based utility (ANCAP 3-star).

The crash occurred after the B-vehicle crossed the centreline (Figure E.13) with both vehicles sustaining frontal offset impact damage.

The A-vehicle driver was hospitalised and sustained multiple AIS 2 injuries (chest, spine, lower extremity) and AIS 1 facial injuries. The dual frontal airbags deployed in the crash and the seat belt was worn. The B-vehicle driver did not require transport to hospital and was otherwise uninjured; both frontal airbags deployed.

Based on the crash reconstruction, the travel speed estimate for the A-vehicle was 59.8 km/h while the B-vehicle driver was travelling at an estimated 72 km/h, noting that the speed limit was 60 km/h. The A-vehicle speed at impact was 53.4 km/h having applied hard braking but only for a very short duration. The B-vehicle speed at impact was 72 km/h (Table E.5).

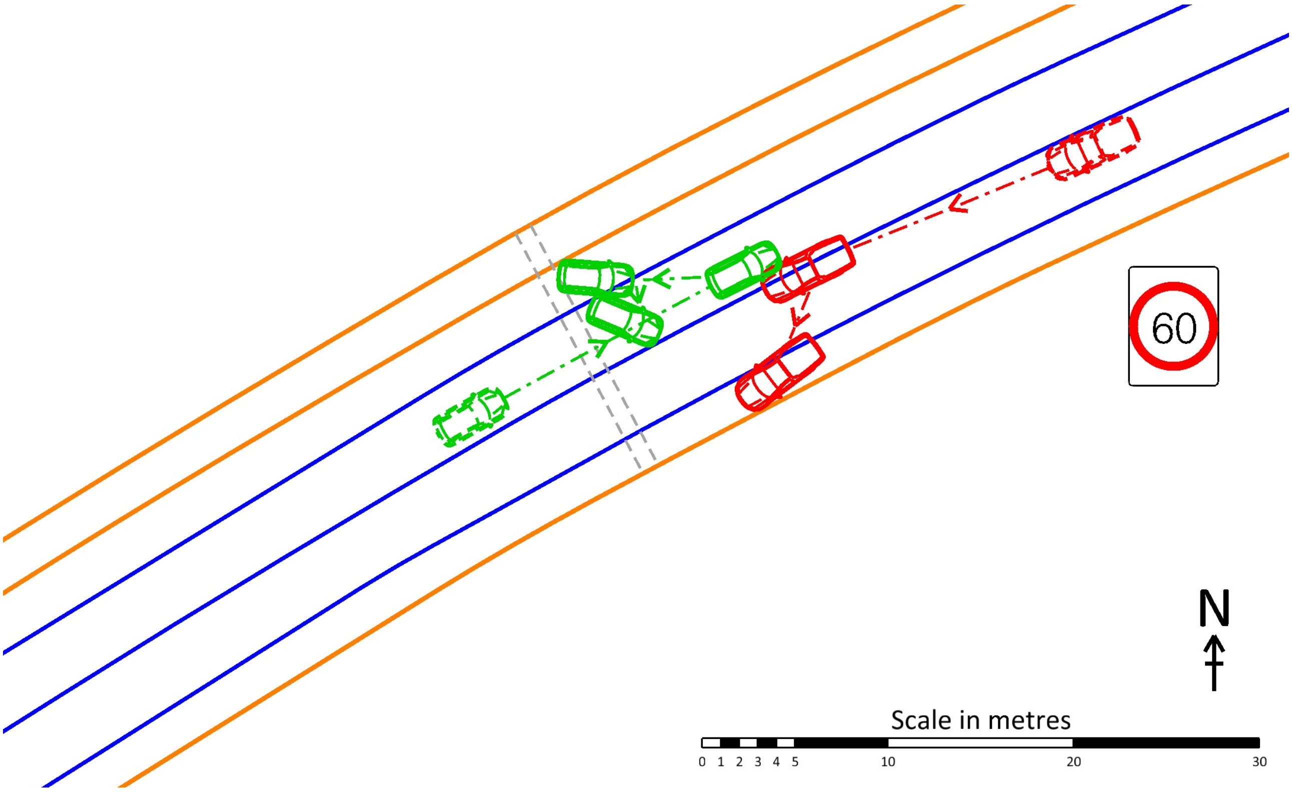


FIGURE E.13 CRASH LOCATION AND VEHICLE MOVEMENTS

E.3.1.2 Interventions

Two speed reduction measures were modelled:

1. Reduced speed limit from 60 km/h to 50 km/h (- 10 km/h).
2. Reduced speed limit from 60 km/h to 40 km/h (- 20 km/h).

In addition, it was assumed that the B-vehicle driver would comply with the revised speed limit but would otherwise not change their travel path. Similarly, it was expected that the A-vehicle driver pre-crash behaviour would not change.

E.3.1.3 Crash reconstruction parameters for the intervention scenarios

The A-vehicle was matched by make and model. The B-vehicle was matched by manufacturer and mass; a sedan model was used in place of a utility in the reconstruction due to a lack of a car-based utility in the available vehicle library.

The trajectories of both vehicles were modelled with the B-vehicle crossing the centreline of the road. The friction coefficient used was 0.80 and a road slope of 2.2° was modelled. A secondary impact by the A-vehicle with a trailing C-vehicle occurred but is not described in detail here, noting that the impact speed was 15.1 km/h with the impact point being the back left panel of the vehicle.

The B-vehicle was estimated to be travelling at 72.0 km/h prior to the impact, with the speed limit being 60 km/h. The B-vehicle crossed the centreline and impacted the A-vehicle at 72 km/h; the A-vehicle was travelling at 53.4 km/h at the time of impact (Table E.5).

Reduced speed limits were modelled and with the B-vehicle driver being modelled as complying with the lower speed limits. The braking points for the A-vehicle were used in the alternative scenarios.

E.3.1.4 Crash outcomes

The damage profile of both vehicles in the actual crash scenario was extensive on the front-right side. The A-vehicle also experienced a secondary impact (left side, rear) with the bridge due to the lighter vehicle rotating in the crash. The reduced speed limit scenarios resulted in significantly less damage to both vehicles, noting the B-vehicle driver was modelled as complying with the lower speed limit. This is seen in all metrics presented in Table E.5 and Figure E.15, as well as in the damage profile presented in Figure E.14.

TABLE E.5 CRASH PARAMETERS FOR THE ORIGINAL CRASH AND LOWER SPEED LIMIT SCENARIOS

VEHICLE / SCENARIO	CRASH PARAMETER							
	TRAVEL SPEED (KM/H)	IMPACT SPEED (KM/H)	DELTA-V (KM/H)	IMPACT POINT	PDOF (⁰)	PEAK FORCE (kN)	KINETIC ENERGY (J)	MAXIMUM CRUSH (MM)
A-VEHICLE								
Original crash	**59.8**	**53.4**	**35.1**	**Narrow frontal offset**	**21.5**	**257.1**	**142,671**	**1295**
Change in speed limit, main carriageway from 60 km/h								
To 50 km/h	49.8 [-16.7]	22.9 [-57.1%]	26.5 [-24.5%]	Narrow frontal offset	20.4	119.8 [-53.4%]	27,001 [+81.1%]	1051 [-18.8%]
To 40 km/h	39.8 [-33.4]	< 1 km/h [-99%]	20.3 [-42.5%]	Narrow frontal offset	19.4	102.3 [-60.2%]	<0.5 [-99.9%]	630 [-51.4%]
B-VEHICLE								
Original crash	**72.0**	**72.0**	**22.0**	**Narrow frontal offset**	**19.0**	**256.7**	**354,243**	**2894**
Change in speed limit, main carriageway from 60 km/h								
To 50 km/h	50.0 [-30.6%]	48.6 [-32.5%]	16.4 [-25.5%]	Narrow frontal offset	18.6	119.6 [-53.4%]	161,798 [-54.3%]	339 [-88.3%]
To 40 km/h	40.0 [-38.3]	40.0 [-44.4%]	17.3 [-21.4%]	Front right corner	17.1	102.3 [-60.1%]	10,994 [-96.9%]	691 [76.1%]

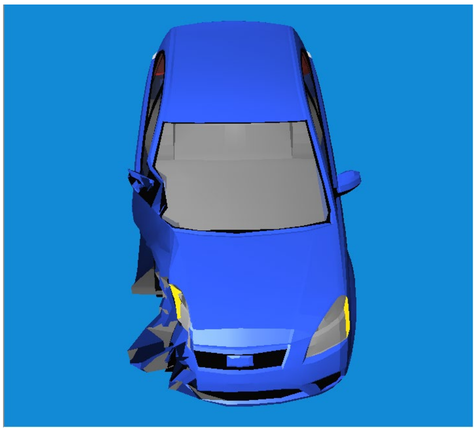
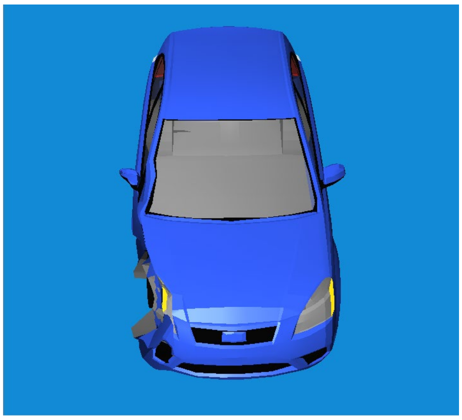
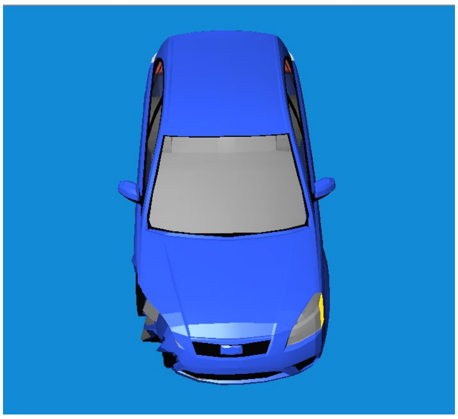
A-VEHICLE	B-VEHICLE
BASELINE CRASH SCENARIO (60 KM/H SPEED LIMIT, B-VEHICLE)	
	
ALTERNATIVE SCENARIO (1): SPEED LIMIT REDUCED TO 50 KM/H	
	
ALTERNATIVE SCENARIO (2): SPEED LIMIT REDUCED TO 40 KM/H	
	

FIGURE E.14 CRASH RECONSTRUCTION REPRESENTATION OF IMPACT DAMAGE

E.3.1.5 Interpretation and summary

Speed limit reductions of 10 km/h and 20 km/h from 60 km/h were modelled. Importantly, compliance with the speed limit was assumed in the alternative scenarios which was not the case in the actual crash scenario. While the impact still occurred, the impact speeds were significantly lower (as expected). This reduced the level of energy in the crash, and the forces experienced by the drivers; the extent of crush was also less.

The effect of the reduction in impact speed and added compliance from the original scenario was significant. These changes had the effect of bringing the crash well within the crash test speed for a frontal offset impact and at the upper margin of the vehicle safety - impact speed boundary condition for the 40 km/h speed limit scenario (see Appendix C). The frontal impact narrow offset damage, despite the lower impact speed, can still be problematic for front seat occupants particularly with respect to lower extremity injuries. Further, with a heavier B-vehicle the A-driver has a less favourable mass ratio. The A-vehicle driver continues to experience moderate levels of crash energy, peak force and intrusion under the alternative scenarios given the damage profile of the vehicle, its mass and its 3-star rating. Having said this, the likelihood of multiple MAIS 2 injuries as per the original scenario would be significantly less. The lower speed limits would also likely have a benefit to the repairability status of both vehicles. The B-vehicle driver would remain uninjured.

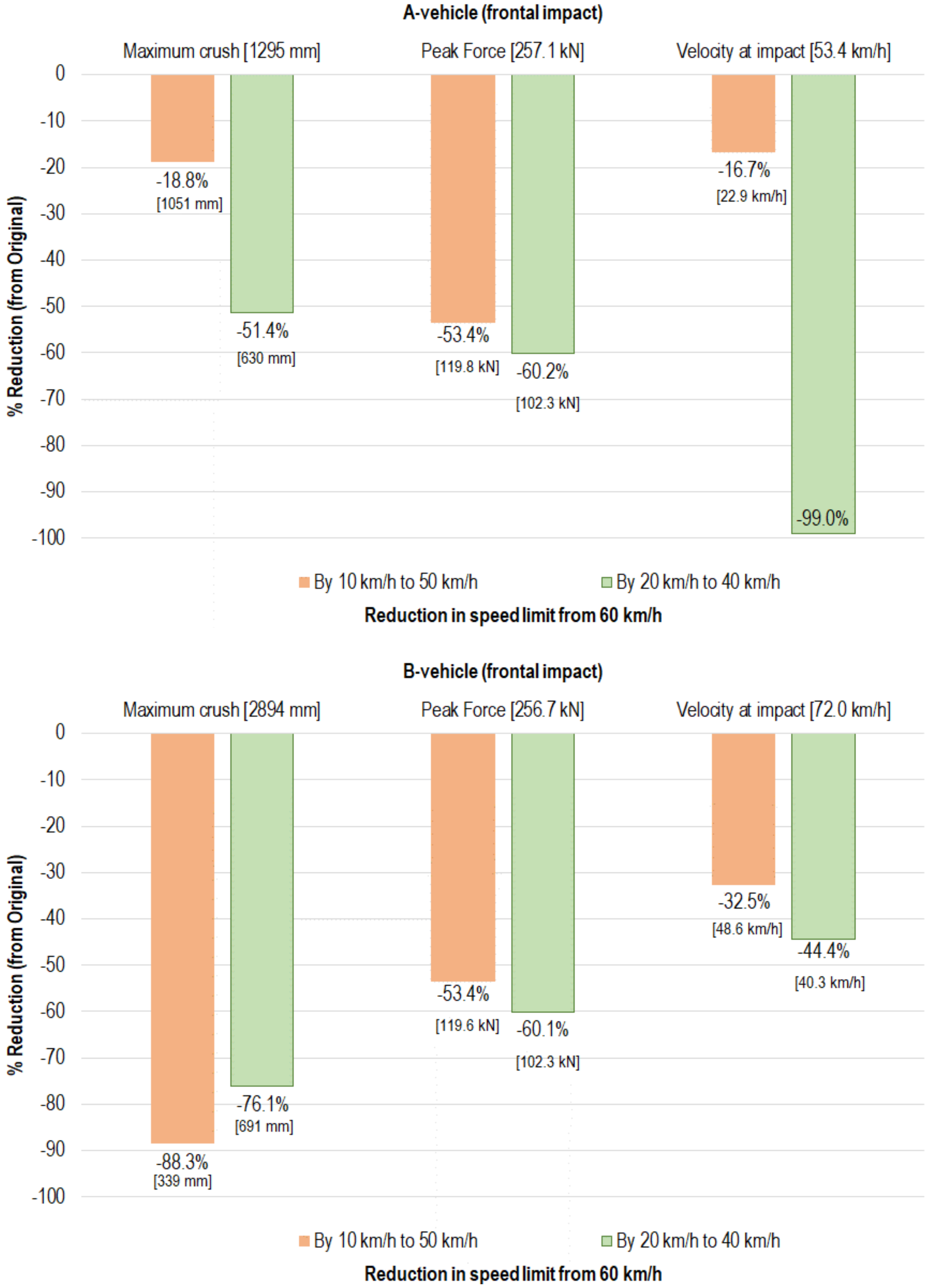


FIGURE E.15 CHANGE IN MAXIMUM CRUSH, PEAK FORCE, AND IMPACT VELOCITY BY SPEED LIMIT CHANGES FOR THE A-VEHICLE AND THE B-VEHICLE RELATIVE TO ACTUAL CRASH SCENARIO

E.3.2 The effect of reducing the speed limit by 10 km/h and 20 km/h on a crash in an 80 km/h speed zone

E.3.2.1 Crash scenario

The crash occurred on a straight section of a sealed undivided C-class road approximately 45 km due-west of central Melbourne. The road had a broken painted centreline. The speed limit was 80 km/h. The surrounding environment was semi-rural farmland. The road had a relatively well-maintained gravel shoulder.

The crash occurred in the afternoon in overcast and dry conditions. The crash involved two drivers in a head-on, frontal impact. The A-vehicle driver was an older male (60 – 70 years) driving a late-1990s 3-star ANCAP rated large car. The vehicle also had a younger male occupant and two young children. All occupants were seriously injured and admitted to hospital.

The B-vehicle driver was male aged 85+ years driving an early 2010 5-star ANCAP rated large car. A front left seat occupant was also present in the vehicle who sustained serious injuries. The driver died.

The crash occurred after the B-vehicle driver crossed the centreline into the path of the oncoming A-vehicle (Figure E.16). The vehicles were the same make and model but differed by 3 years in terms of year of manufacture.

The A-vehicle driver sustained multiple MAIS 3 chest and lower extremity injuries plus multiple MAIS 2 (chest, abdomen, lower extremity) and MAIS 1 injuries (head, abdomen). The driver-only front airbag deployed. The seat belt was worn.

Based on the crash reconstruction, the travel speed estimate for the A-vehicle was 82.5 km/h and was travelling at 81.5 km/h at the time of the impact. The pre-crash speed of the B-vehicle driver was 78.0 km/h and was moving at 73.3 km/h at impact. The B-vehicle driver braked immediately prior to impact; the A-vehicle did not.

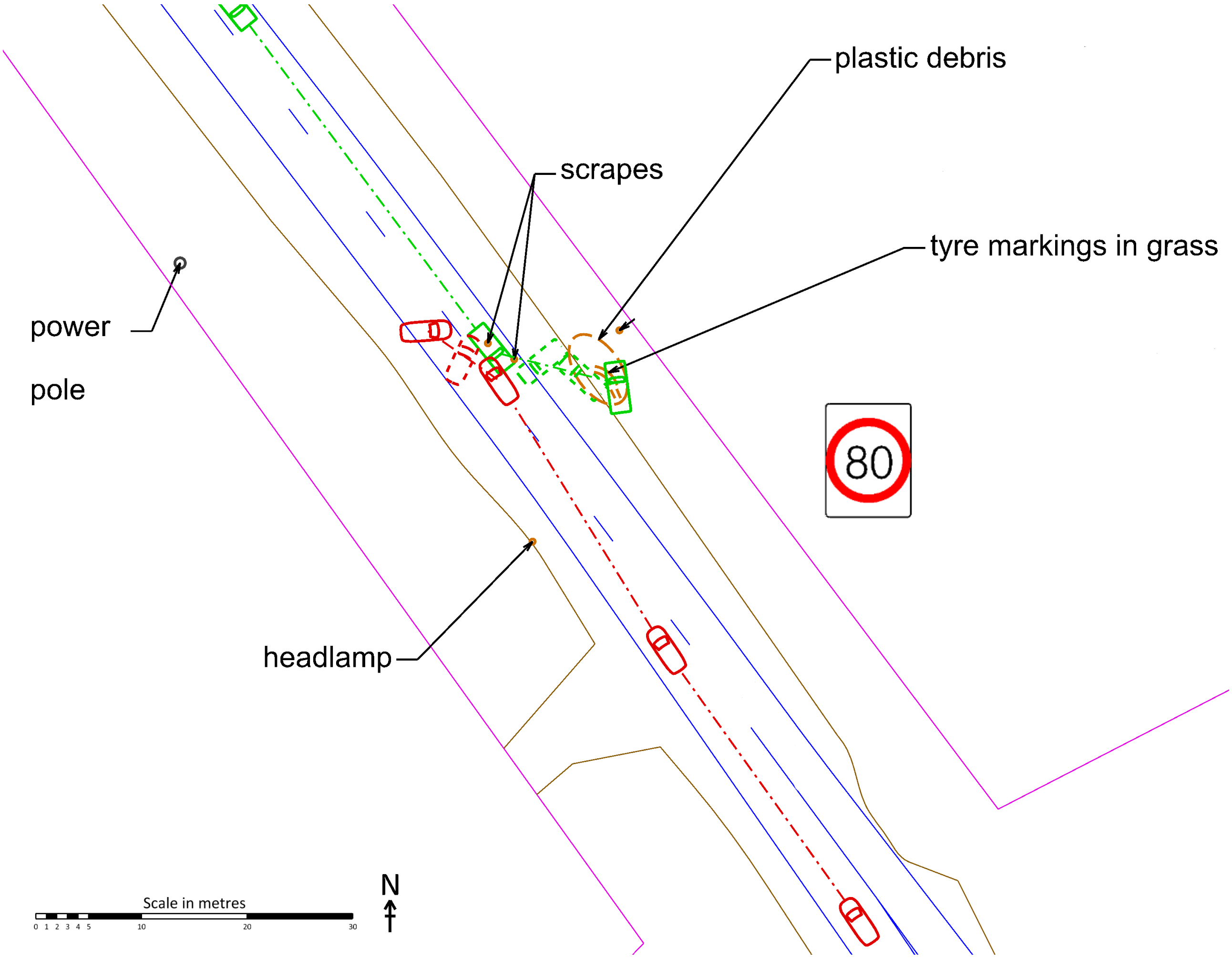


FIGURE E.16 CRASH LOCATION AND VEHICLE MOVEMENTS

E.3.2.2 Interventions

Two speed limit reduction scenarios were modelled:

1. Reduced speed limit from 80 km/h to 70 km/h (- 10 km/h).
2. Reduced speed limit from 80 km/h to 60 km/h (- 20 km/h).

Compliance with the speed limit was assumed. It was also assumed pre-crash behaviours would not change.

E.3.2.3 Crash reconstruction parameters for the intervention scenarios

The A-vehicle was matched by type, geometry, and mass. The B-vehicle was matched by manufacturer, type, geometry, and mass.

As the B-vehicle veered across the centreline this behaviour was maintained, as was the braking behaviour. The point on the road where braking was applied in the initial crash scenario was used. The roadway friction coefficient was set to 0.80.

E.3.2.4 Crash outcomes

The damage to both vehicles in the actual crash scenario was extensive (Table E.6, Figure E.17, Figure E.18), noting that the impact occurred well above the current regulatory and ANCAP frontal offset crash test speed. The front structures of both vehicles engaged at high speed and this was reflected in the magnitude of deformation and vehicle crush. The energy of the crash event was high, as was the peak force. The impact was loaded to the right driver side, hence the severe nature of the injuries sustained by that occupant.

The reduction of the speed limit to 70 km/h was associated with a lower crash severity, however the crash energy remained high. As a consequence, the vehicle deformation whilst lower remained significant. In the 60 km/h speed limit alternative scenario, the impact was avoided.

TABLE E.6 CRASH PARAMETERS FOR THE ORIGINAL CRASH AND LOWER SPEED LIMIT SCENARIOS

VEHICLE / SCENARIO	CRASH PARAMETER							
	TRAVEL SPEED (KM/H)	IMPACT SPEED (KM/H)	DELTA-V (KM/H)	IMPACT POINT	PDOF (^{0})	PEAK FORCE (kN)	KINETIC ENERGY (J)	MAXIMUM CRUSH (MM)
A-VEHICLE								
Original crash	**82.5**	**81.5**	**54.6**	**Front right**	**19.2**	**452.3**	**447,005**	**1836**
Change in speed limit, main carriageway from 80 km/h								
To 70 km/h	70.0 [-12.5%]	69.2 [-15.1%]	46.2 [-15.4%]	Front right	19.5	381.1 [-15.7%]	325,520 [-27.2%]	1317 [-28.3%]
To 60 km/h	60.0 [-25.0%]	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided
B-VEHICLE								
Original crash	**78.0**	**73.3**	**48.8**	**Front right**	**12.6**	**452.8**	**376,186**	**1555**
Change in speed limit, main carriageway from 80 km/h								
To 70 km/h	70.0 [-10.3%]	53.5 [-27.0%]	46.6 [-4.5%]	Front right	12.4	381.7 [-15.7%]	203,856 [-45.5%]	1534 [-1.4%]
To 60 km/h	60.0 [-23.1%]	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided	Avoided

Note: this is the B-vehicle speed as the ‘bullet’ vehicle.

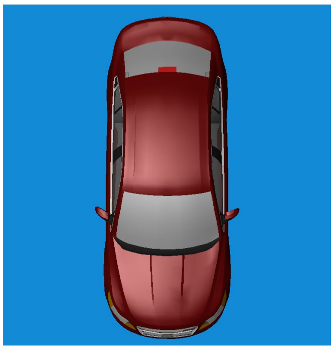
In addition to the above, a simulation was performed to ‘force’ a vehicle impact in the 60 km/h scenario, however this required steering inputs to be manipulated to ensure the crash event occurred. In this scenario, the crash was modelled as having occurred at 60 km/h. The delta-V for the A-vehicle was 13.7 km/h and 15.5 km/h for the B-vehicle. The speed at impact of the A-vehicle was 49.5 km/h and 58.6 km/h for the B-vehicle. With the frontal crash configuration, the injury severity of the occupants would be significantly lower in this scenario however it is highly probable the occupants would be injured and would be transported to hospital.

A-VEHICLE	B-VEHICLE

BASELINE CRASH SCENARIO (80 KM/H SPEED LIMIT, B-VEHICLE)

ALTERNATIVE SCENARIO (1): SPEED LIMIT REDUCED TO 70 KM/H

ALTERNATIVE SCENARIO (2): SPEED LIMIT REDUCED TO 60 KM/H



No impact

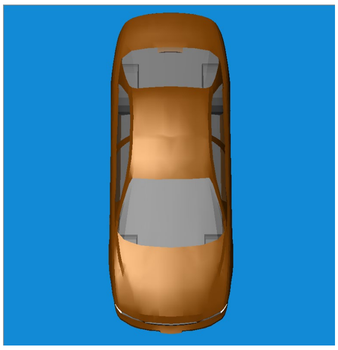


FIGURE E.17 CRASH RECONSTRUCTION REPRESENTATION OF IMPACT DAMAGE

E.3.2.5 Interpretation and summary

The injury severity of the actual crash scenario was extreme. The driver of the B-vehicle died, the driver of the A-vehicle sustained multiple MAIS 3 injuries, and all other persons involved were injured and hospitalised. To recap, the head-on crash occurred on an undivided C-class road where the speed limit was 80 km/h. Vehicle-A was travelling 2.5 km/h above the speed limit while the B-vehicle driver was 2 km/h below the speed limit. The B-vehicle driver became distracted and veered across the centreline into the path of an oncoming vehicle with little time for braking.

The effect of a 70 km/h speed limit was modelled, representing a 10 km/h reduction in the speed limit. The effect on the crash outcome of this change is significant. The impact speed for the A-vehicle reduced to 69.2 km/h (cf. 81.5 km/h) while the B-vehicle impact speed reduced to 53.5 km/h from 73.3 km/h. This resulted in a substantial reduction in vehicle deformation. The high degree of force however directly loaded the right driver side; as a consequence, the B-vehicle driver would likely be seriously injured, principally due to age-based frailty. It is likely the A-vehicle driver would continue to sustain an MAIS 3 injury (likely lower extremity) given the impact speed remaining above the frontal offset crash test speed (i.e., 64 km/h, see Appendix C) and the 3-star ANCAP vehicle safety rating. However, the severity of other injuries would likely be less. As shown, a speed limit of 60 km/h results in the crash being avoided altogether holding all else equal. The reduction in trauma seen by this change is profound.

To conclude, this crash highlights the severe nature of head-on crashes when speed limits are misaligned given foreseeable crash types, the safety profile of the vehicle fleet and the person-based factors such as driver (and passenger) age. Based on the analysis presented here, reducing the speed limit by 10 km/h and 20 km/h delivers significant road safety benefits in this common crash scenario.

In practical terms, it is noted that the entire length of the road where the crash occurred was approximately 20 km. Hence a speed limit reduction to 70 km/h (from 80 km/h) would translate to an extra two-minute travel time while a 60 km/h speed limit would translate to an extra 5 minutes to drive the road end-to-end. This highlights the points made in *ECIS Report 1* concerning the trade-off between safety and mobility and the need to create an inherently safe road transport system.

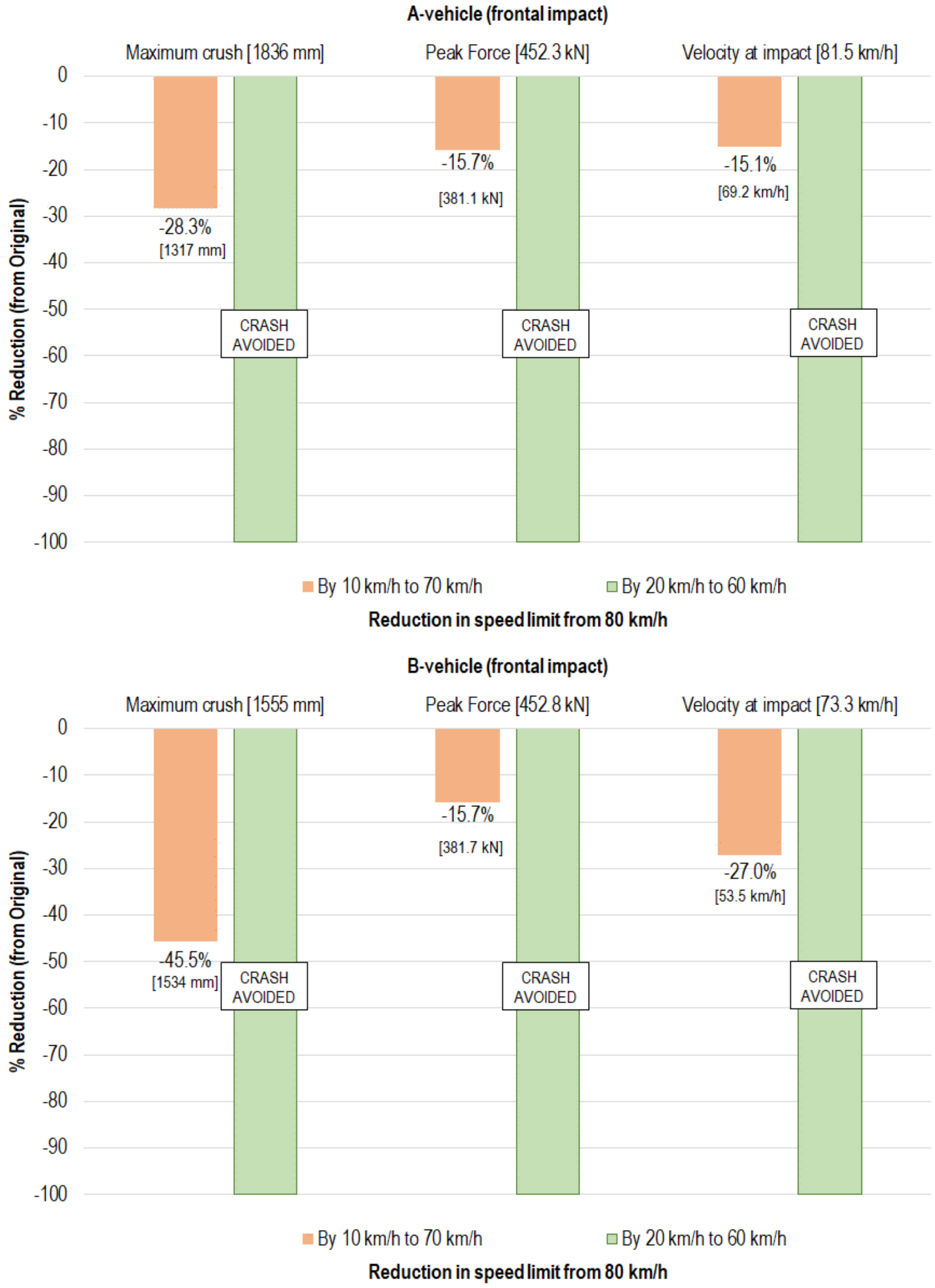


FIGURE E.18 CHANGE IN MAXIMUM CRUSH, PEAK FORCE, AND IMPACT VELOCITY BY SPEED LIMIT CHANGES FOR THE A-VEHICLE AND THE B-VEHICLE RELATIVE TO ACTUAL CRASH SCENARIO

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APPENDIX F OVERVIEW OF DATA USED IN THIS REPORT

This Appendix presents an overview of the data used in each chapter in this report. This is provided so as to show the fit of the data used in this report in relation to *ECIS Report 1* and across each chapter of this report.

To recap, the ECIS Case study enrolled 400 hospitalised drivers. As both involved drivers were enrolled to the ECIS Case study in seven crashes, the ECIS program included 393 unique crashes. These crashes were classified as Lane Departure crashes (n = 202 drivers; n = 199 crashes), Across Path crashes (n = 120 drivers; n = 117 crashes), Rear Impact crashes (n = 69 drivers; n = 68 crashes), and 'Other' crashes (n = 9 drivers; n = 9 crashes). Full details are of the data collection methods and results are provided in *ECIS Report 1*.

In total, 340 crashes (347 drivers, ECIS Cases) were successfully reconstructed with pre-crash travel speed and impact speed being obtained. The Type-A crash reconstruction method using *HVE* was completed for 170 crashes (48.5%), while 177 crashes (51.5%) were reconstructed using the Type-B crash reconstruction method. The reader is referred to *ECIS Report 1* for full details of the data collection and crash reconstruction methods, and Appendix A of this report.

For the ECIS Control study, 228 crash sites from the ECIS Case Study were used. As described in *ECIS Report 1*, the 'free' speed of all vehicles observed within a minimum 30-minute window each side of the crash time were recorded using a laser speed camera.

As described in the *Introduction,* this report set out to address questions specific to vehicle speed. The data used in each chapter was selected on the basis of being the data most suited to examining each specific question. It is stated upfront that the data used in each chapter represents a subset of the overall dataset. Table F.1 provides an overview of the data used in each chapter, including the rationale for its use. Full details of the data used is provided within each chapter and is not repeated here.

TABLE F.1 DATA USED IN THIS REPORT

CHAPTER	INTENT OF CHAPTER AND TYPE OF ANALYSIS	DATA SOURCE(S), DESCRIPTION AND RATIONALE
2	To examine the relationship between the speed limit and vehicle travel speed. Analysis: correlation analysis.	• Subset of ECIS Case data and ECIS Control data. • Limited to the travel speed of vehicles involved in Lane Departure crashes where a single vehicle or a maximum of two vehicles were involved. Travel speed for crash involved vehicles was determined using Type-A and Type-B crash reconstruction methods. Data from 172 Lane Departure crashes was used. All vehicles were included, irrespective of whether matched ECIS Control data were available. • Includes all drivers (vehicles) measured as ECIS Control drivers associated with ECIS Lane Departure crashes including non-responders as driver age and driver sex were not required. Control data were available for 102 Lane Departure crashes. • Excludes Across Path, Rear Impact, and 'Other' crashes due to the complexity of vehicle movements. The intent was to use the 'free' travel speed of vehicles not performing any manoeuvres or where another vehicle may have influenced vehicle speed.
3	To examine the association between travel speed and crash risk. Analysis: conditional logistic regression.	• Subset of ECIS Case data and ECIS Control data. • 170 crashes initially included. Accounting for the removal of crashes where AOD was indicated, the analysis set consisted of drivers involved in 80 Lane Departure crashes and 66 Across Path crashes where a maximum of two vehicles were involved. ○ Adopting a conservative approach, travel speeds determined using the Type-A crash reconstruction methods were used given the additional validation step over and above the Type-B crash reconstruction travel speed estimates. • Used the measured travel speed of ECIS Control drivers who provided informed consent and returned their completed ECIS

		Control Questionnaire to the ECIS team as driver age and driver sex were required in the analysis. • Excluded Rear Impact crashes and 'Other' crashes due to complexity of vehicle movements, the number of crash sub-types and the sample size.
4	To examine the relationship between vehicle travel speed and vehicle speed at impact. Analysis: correlation analysis.	• Subset of ECIS Case data. • Vehicles involved in 304 crashes, including 167 Lane Departure crashes (n = 227 vehicles), 105 Across Path crashes (n = 204 vehicles) and 32 Rear Impact crashes (n = 54 vehicles, not stationary). • Travel speed and impact speed derived by Type-A and Type-B crash reconstruction methods. • Excluded crashes where 3 or more vehicles were involved and/or the crash involved multiple complex vehicle movements.
5	To examine the relationship between impact speed and injury. Analysis: logistic regression.	• Data from 347 ECIS Case drivers was used. • Impact speed derived by Type-A and Type-B crash reconstruction methods
6 / Appendix E	To illustrate the effect of speed limit reduction scenarios on crash outcomes. Analysis: case series.	• Ten ECIS Cases were selected. These met pre-defined criteria including crash type, location, the number of vehicles involved and the speed limit. • Includes: ○ Three intersection crashes (60 km/h, 80 km/h, 100 km/h speed limit). ○ Three single-vehicle run-off-road crashes (60 km/h, 80 km/h, 100 km/h speed limit). ○ Three head-on crashes (60 km/h, 80 km/h, 100 km/h speed limit). ○ One rear impact (70 km/h). • Crashes were reconstructed using the Type-A crash reconstruction method. The alternative crash scenarios modelling speed limit reductions and speed limit compliance used these crash reconstructions as a base.

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Further information

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