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TITLE

The safety benefits of limiting ISA: a pilot study using real world crash situations

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ABSTRACT

Limiting Intelligent Speed Adaptation (ISA) is an in-vehicle technology that seeks to eliminate speeding by limiting the speed of the vehicle to the speed limit. This report describes a pilot study that assesses a particular method of evaluating limiting ISA using real world crashes and information from event data recorders (EDRs). The EDR files and additional details regarding the crash were obtained from the National Automotive Sampling System - Crashworthiness Data System (NASS-CDS) database from the United States of America (USA). A small sample of 59 cases from 2013 was used in this pilot study. It was estimated that, with limiting ISA, 13 of these could be avoided completely, serious injury crashes could be reduced by 62%, and moderate injury crashes by 22%. It was concluded that limiting ISA may have the potential to produce large reductions in injuries, though these may be smaller in jurisdictions with superior speed compliance. The study also found that less than 10% of EDR files within the NASS-CDS database were suitable and that use of EDR data can restrict the crash types and vehicle types in the sample. However, EDR data that is suitable appears to be more accurate and complete than that from alternative sources like crash reconstructions. It is recommended that a full study of this type be undertaken using a larger sample of EDR data from the NASS-CDS database and that the feasibility of an Australian EDR database matched to injury data should be investigated. In a full study, methods to reduce the time taken to identify suitable cases with the NASS-CDS database should be investigated.

KEYWORDS

Intelligent speed adaptation (ISA), Speeding, Accident reduction, Injury prevention, Event data recorder (EDR)

Summary

Speed limits are set by road authorities to control the maximum speed at which vehicles travel. However, drivers may still travel above the speed limit intentionally or unintentionally. Limiting Intelligent Speed Adaptation (ISA) is an in-vehicle technology that seeks to eliminate speeding by limiting the speed of the vehicle to the speed limit.

In 2010, Centre for Automotive Safety Research (CASR) staff developed a method for calculating the safety benefits of technologies that reduce a vehicle's speed prior to a crash. In contrast to previous studies on ISA, this method takes into account the specific circumstances and outcome of each crash. This report describes a pilot study into the application of this method to limiting ISA, while also exploring the use of information from event data recorders (EDRs) contained within the National Automotive Sampling System - Crashworthiness Data System (NASS-CDS) database from the United States of America (USA).

The overall methodological process included: developing a model describing the functionality of limiting ISA, extracting a sample of cases from NASS-CDS, applying the limiting ISA model to this sample to determine a new closing impact speed and estimating the effect on injury outcomes. This process allowed the benefit of limiting ISA to be estimated.

Data was extracted from NASS-CDS cases from 2013, including 806 EDR files. However, many of these cases were rejected for several reasons, including: the EDR file did not contain all the necessary data, excessive wheel slip rendered the EDR speeds inaccurate, the EDR file was from the struck rather than the striking vehicle, the closing speed could not be accurately determined, or injury severity was unknown. The size of the sample for this pilot study was 59 cases.

ISA was found to have the greatest effect for serious injury crashes (62% reduction), while moderate injury crashes were also reduced substantially (27%). Of particular note is that 13 of the 59 crashes (22%) would have been avoided altogether. The rise in non-injury crashes is a result of a proportion of the injury crashes still resulting in impacts, but at speeds that are unlikely to be injurious. The reduction in minor and moderate injury crashes is tempered by similar transference from serious injury crashes.

It was concluded that:

- Limiting ISA may have the potential to produce large reductions in injuries, particularly serious injuries.
- The large benefits found it this study may be smaller in jurisdictions with superior speed compliance.
- The NASS-CDS database is a large source of EDR data but limits the analysis to crashes involving light vehicles that are less than ten years old.
- Less than 10% of EDR files within the NASS-CDS database were suitable for this type of analysis. This can result in a large amount of time being spent simply identifying suitable crashes. Methods to reduce this time would be worthwhile for a larger sample.
- The EDR data that is suitable appears to be more accurate and complete than data from reconstructions.
- Use of EDR data can restrict the crash types and vehicle types in the sample.

These conclusions lead to the following recommendations:

- A study with a larger sample should be undertaken to provide a more robust result.
- This study should use EDR data from the NASS-CDS database
- Methods to reduce the time taken to identify suitable crashes within the NASS-CDS database should be investigated.
- The feasibility of an Australian EDR database matched to injury data should be investigated.

Contents

1 Introduction

Speed is major factor in the frequency and severity of road crashes. Speed limits are set by road authorities to control the maximum speed at which vehicles travel. However, drivers may still travel above the speed limit intentionally or unintentionally. Intelligent Speed Adaptation (ISA) is an in-vehicle technology that seeks to eliminate speeding through warnings to the driver, or by electronically limiting the speed of the vehicle. It has shown great potential to reduce speeds, and therefore crashes, in both international and Australian trials. Unsurprisingly, ISA systems that recognise the current speed limit and physically limit vehicle speeds accordingly (rather than just providing a warning) have been shown to be the most effective (Päätalo, Peltola & Kallio, 2001; Adell, Várhelyi & Hjälmdahl, 2008; Tate & Carsten, 2008)

Previous studies have calculated the effect of ISA on crashes using either Elvik's power model (Elvik, Christensen & Amundsen, 2004) or Kloeden's relative risk curve (Kloeden, McLean, Moore & Ponte, 1997; Kloeden, Ponte & McLean, 2001). Elvik's power model has been used to equate changes in mean speed with changes in crash frequency at different injury severities (e.g. Driscoll, Page, Lassarre & Ehrlich, 2007). Kloeden's model has been used to predict the difference in casualty crashes for a given change in speed distribution (e.g. Tate & Carsten, 2008; Doecke, Anderson & Woolley, 2010).

In 2010, Centre for Automotive Safety Research (CASR) staff developed a method for calculating the benefits of technologies that reduce a vehicle's speed prior to a crash. In contrast to previous studies on ISA, this method takes into account the specific circumstances and outcome of each crash. The effect of the technology (in this case ISA) is applied to the pre-crash trajectory to determine a new impact speed. This new impact speed is then used to estimate a new probability of different levels of injury, taking into account the actual injury severity that occurred in the real life crash. This method has previously been applied to investigations of autonomous emergency braking (Anderson *et al*., 2012; Doecke, Anderson, Mackenzie & Ponte, 2012; Anderson, Doecke, Mackenzie & Ponte, 2013) and connected vehicles (Doecke, Grant & Anderson, 2015).

This report describes a pilot study into the feasibility of applying the method to ISA, while also exploring the use of information from event data recorders (EDRs) contained within the National Automotive Sampling System - Crashworthiness Data System (NASS-CDS) database from the United States of America (USA).

2 Method

An overview of the process by which the benefits of limiting ISA was determined, is described graphically in Figure 2.1. The process was as follows:

- A model describing the functionality of limiting ISA model was developed.
- A sample of crash data with the necessary details (travel speed, impact speed, closing speed, braking time to collision [TTC], injury severity) was extracted from an appropriate database.
- The effect that limiting ISA had on the impact speed (and hence the closing speed) in the relevant crashes, was modelled.
- The influence of the reduced closing impact speed on injury severity was estimated.
- The benefit of limiting ISA was estimated by summing the change in injury probabilities in the individual crashes and comparing to the total of the original injuries.

Each of these elements shown in Figure 2.1 will be described below.

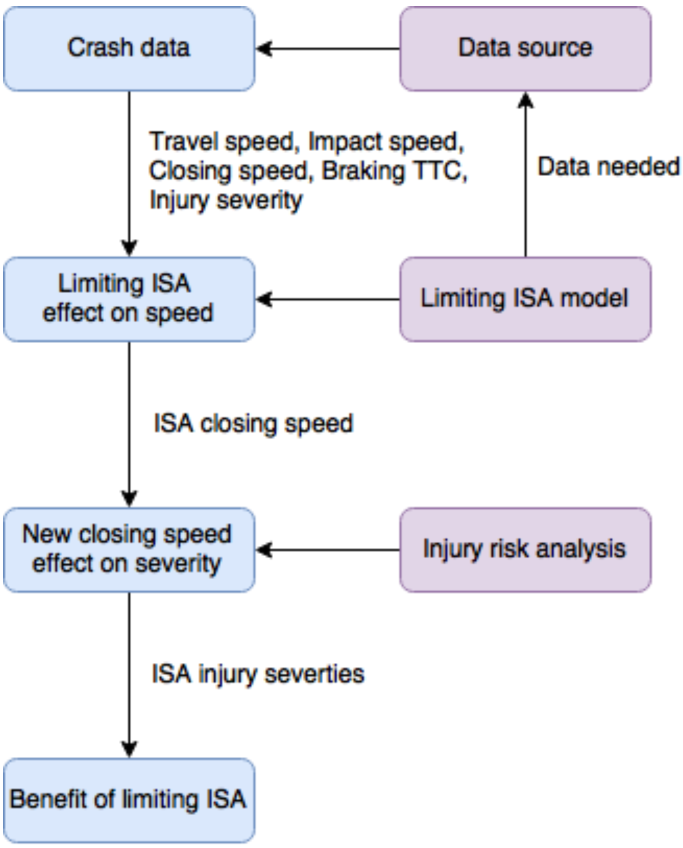

Figure 2.1
Methodological flow of calculating the safety benefit of limiting ISA

2.1 Limiting ISA model

The objective of limiting ISA is to limit the travel speed of a vehicle to the speed limit. For the purpose of this analysis we assumed that limiting ISA is fully effective in this objective, always limiting travel speeds to the speed limit. When limiting ISA reduces the travel speed, the impact speed will also be reduced. These new speeds are referred to as the ISA travel speed and the ISA impact speed. The flow diagram for the limiting ISA system model that was used to calculate these new speeds is shown in Figure 2.2.

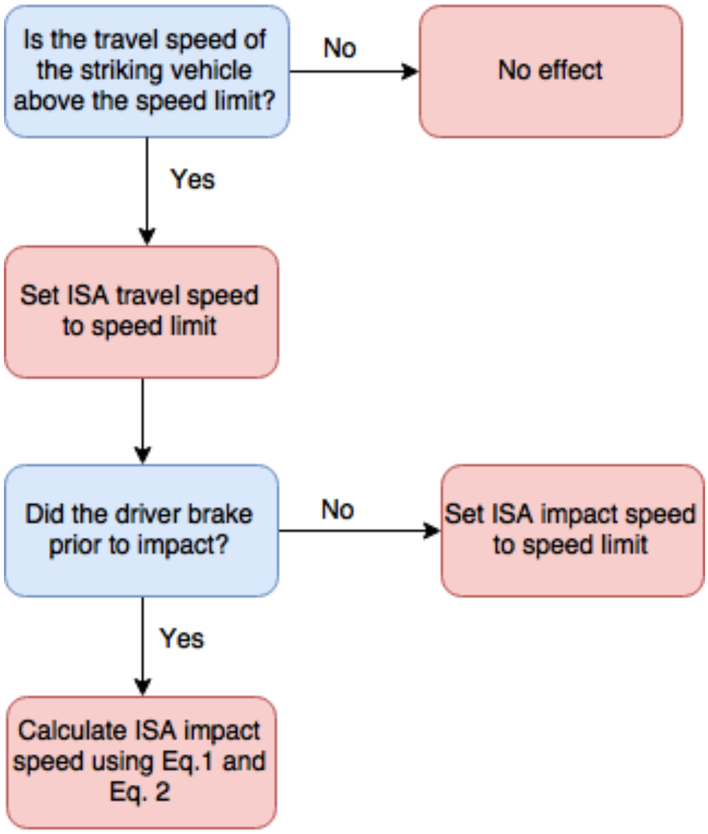

Figure 2.2
Flow diagram of the limiting ISA system model

The equations used by the model are:

$$d_{ISA} = \frac{TTC_{braking}(v_t+v_i)}{2} + t_{reaction}(v_t - v_{t,ISA}) \quad (1)$$

$$v_{i,ISA} = \sqrt{v_{t,ISA}^2 + 2ad_{ISA}} \quad (2)$$

where $$a = \frac{v_i - v_t}{TTC_{braking}} \quad (3)$$

d_{ISA} = distance from impact point when braking commences with limiting ISA
$TTC_{braking}$ = original time to collision when braking commenced
v_t = original travel speed
v_i = original impact speed
$t_{reaction}$ = reaction time
$v_{t,ISA}$ = travel speed with limiting ISA
$v_{i,ISA}$ = impact speed with limiting ISA
a = average acceleration from braking point to impact point

These equations reveal the pre-crash data that is required in order to calculate the ISA impact speed: the original travel speed, original impact speed, the original time to collision (TTC) when the driver began braking, and a reaction time.

Historically, data on speed and braking TTC could only be gained from reconstructions performed following a detailed forensic examination of a crash. In recent years these reconstructions often struggle to accurately estimate travel speed and braking TTC due to the advent of anti-lock brakes which result in a lack of clear pre-impact braking skid marks.

This information can now be obtained through data downloaded from a crashed vehicle's event data recorder (EDR). Since the 1990's some vehicles have used EDRs to record selected sensor data in the event of a crash. These data can include the speed of the vehicle and brake usage up to five seconds prior to the impact.

2.2 Data

2.2.1 Source

The largest source of EDR data is the National Highway Traffic Safety Administration's (NHTSA) National Automotive Sampling System - Crashworthiness Data System (NASS-CDS) in the USA. While EDR data has been collected in recent years in Australia as part of CASR's in-depth crash investigations and the TAC-MUARC Enhanced Crash Investigation Study, far fewer crashes have been investigated in these studies and far less of the vehicle fleet have downloadable EDR data in Australia. NASS-CDS data is publically available, including the original EDR files. NASS-CDS was the data source chosen for this study.

2.2.2 Sample derivation

Data was extracted from the NASS-CDS database for a number of crashes that occurred in 2013. NASS-CDS contains data on 3,385 crashes from 2013. EDR data was available for 1,234 vehicles involved in these crashes. Because of the time consuming nature of the data extraction, and the limited resources available for the pilot study, only 806 EDR files from 2013 were examined. For a crash to be included it needed to fulfil the following criteria:

- EDR file contained travel speed, impact speed, braking TTC
- EDR speed data was not significantly affected by wheel slip
- EDR data available for the striking vehicle
- Known closing impact speed
- Known speed limit
- Known injury severity

Only 59 of these cases fulfilled all the criteria and were included in the pilot study. The reasons for the high rejection rate are discussed below.

Many EDR files did not contain all the essential data: travel speed, impact speed and braking TTC. General Motors EDRs do not contain a precise impact speed due to the speed data being asynchronous to the airbag accelerometers that determine impact and data being recorded at 2 Hz. This results in the final speed recording being at an undetermined time between 0 and 0.5 s before impact. All General Motors EDR files are therefore unusable for the purpose of this pilot study. Furthermore, some earlier Toyota EDR's did not record vehicle speed. This represented a substantial reduction in the usable EDR files.

Wheel slip can cause the speed data contained in the EDR data to be inaccurate. Modern vehicles most commonly measure their speed using wheel speed sensors, though some will still use sensors that measure the rotation of the drive shaft. In either case, if the wheel(s) that are associated with the speed measurement experience significant slipping due to braking or sideslip (sliding sideways) the speed that is measured by these sensors will be less than the true speed of the vehicle. For this reason crashes where the striking vehicle lost control prior to impact and developed a significant sideslip angle, could not be included. It should be noted that with extra reconstruction effort the travel and impact speed of these vehicles could be determined for future work. All vehicles that had otherwise suitable EDR data should have anti-lock brakes that prevent excessive slip under braking, however, momentary spikes in slip can still occur. Error in the impact speed due to excessive longitudinal slip under braking was checked for by calculating the acceleration and comparing the value to known maximums.

Many of the EDR files came from struck vehicles and are therefore not relevant for this pilot study. In the case of head on crashes either vehicle could be defined as the striking vehicle, though there are other difficulties with head on crashes described below. Intersection crashes where the turning vehicle struck the through vehicle were also excluded, though such crashes are relatively rare.

Many rear and head on crashes were excluded due to an unknown closing impact speed. The method for estimating injury reductions from impact speed reductions (explained Section 2.3) relies on closing speed. For most intersection crashes the contribution to the closing speed of the struck vehicle is minimal. However, for in-line crash configurations (head on, rear end) the struck vehicles contribution can be significant. For rear end crashes this meant that crashes where the struck vehicle was known to be moving at impact, and the NASS-CDS database did not contain a reported speed, had to be excluded. Head on crashes could only be included under similar conditions.

NASS-CDS does not have complete injury data due to limited data collection for vehicles more than 9 years old. For a crash to be included in NASS-CDS it must have at least one vehicle that is less than ten years old. For crashes where one or more vehicles are ten or more years old only limited information is recorded for those vehicles. The injuries that the occupant(s) of that vehicle sustained are not recorded. As the method of estimating injury reductions (see Section 2.3) requires an overall crash severity these crashes had to be excluded. There are also some crashes within NASS-CDS in which detailed data is missing for a vehicle and occupants despite the vehicle meeting the age requirement, possibly due to difficulties in locating the vehicle.

Table 2.1 shows the final sample of NASS-CDS crashes by crash type and maximum abbreviated injury score (MAIS). It should be noted that the crash types have been adjusted to reflect an environment where vehicles travel on the left. All common crash types are represented except for rollover. Hit fixed object was the crash type most prevalent in the sample, followed by right angle crashes. The clear majority of the crashes involved minor or moderate injury. Note that non-injury crashes are included in NASS-CDS as their minimum severity criterion is that a vehicle is towed. These have been included in the sample as ISA has the potential to prevent the crash altogether.

Table 2.1
Sample of NASS-CDS crashes by crash type and injury level

Crash type	MAIS			Total
	0 (non-injury)	1-2 (minor/moderate)	3+ (serious injury)	
Right angle	3	7	3	13
Right turn - adjacent	1	3	0	4
Right turn - opposing	1	6	1	8
Rear end	3	5	0	8
Head on	1	4	1	6
Hit fixed object	2	14	3	19
Other	0	1	0	1
Total	11	40	8	59

2.2.3 Extraction of key data

An example of the EDR pre-crash data and the key data points from which the information is extracted is shown in Figure 2.3. For the EDR file shown, the variables used are 'Time', which represents TTC, 'Speed vehicle indicated', and 'Service brake, on/off'. Note that the names and ways in which these are displayed vary between vehicle manufacturers, models and model years. Travel speed was defined as the speed at the last data point prior to data point where braking had begun (80 km/h). The impact speed was defined as the speed when the pre-crash data showed a time of zero. The braking TTC was interpolated from the pre-crash time immediately prior to braking (2.5 s) the first data point at which braking was present (2.0s), and the difference in speed found between the first two time points of braking (8 km/h between TTC 2 and 1.5s). For the example shown below this would be 2.31 s ((5/8x0.5)+2), however, allowance was made for brake pressure rise time by rounding up to the nearest 0.1 s, giving a braking TTC of 2.4 s.

Pre-Crash Data -5 to 0 sec [2 samples/sec] (First Record)

Times (sec)	Speed vehicle indicated MPH [km/h]	Accelerator pedal, % full	Service brake, on/off	Engine RPM	ABS activity (engaged, non-engaged)	Brake Powertrain Torque Request	Driver Gear Selection
- 5.0	51 [82]	3.4	Off	1,266	non-engaged	No	Drive
- 4.5	50 [81]	4.2	Off	1,296	non-engaged	No	Drive
- 4.0	50 [81]	3.7	Off	1,310	non-engaged	No	Drive
- 3.5	50 [81]	0.0	Off	1,254	non-engaged	No	Drive
- 3.0	50 [80]	0.0	Off	1,224	non-engaged	No	Drive
- 2.5	50 [80]	0.0	Off	1,224	non-engaged	No	Drive
- 2.0	47 [75]	0.0	On	1,142	non-engaged	No	Drive
- 1.5	42 [67]	0.0	On	1,024	non-engaged	No	Drive
- 1.0	36 [58]	0.0	On	1,012	non-engaged	No	Drive
- 0.5	30 [49]	0.0	On	884	engaged	Yes	Drive
0.0	22 [36]	0.0	On	818	engaged	No	Drive

Travel speed   Impact speed   Data points used to interpolate braking TTC

Figure 2.3
Example of EDR pre-crash data and the key data points

Reaction time cannot be obtained from EDR files and must be assumed. Green (2000) analysed many prior studies on reaction time and found that the perception-brake reaction time for unexpected events while driving is approximately 1.5 seconds. This is the value that is used in this report.

2.3 Estimation of injury reduction

Three injury severity categories are used in this study and those categories and their corresponding defined injury descriptions are shown in the Table 2.2.

Table 2.2
Categories of injury severity

MAIS Severity	Injury Description
MAIS 0	No injury
MAIS 1 - 2	Moderate Injury
MAIS 3 +	Serious Injury

The flow diagram for estimating the potential crash injury reduction due to a speed limiting ISA system is shown in Figure 2.4. The method for redistributing the injury probabilities is described in detail in Anderson *et al*. (2012) but is summarised with two working examples in this section.

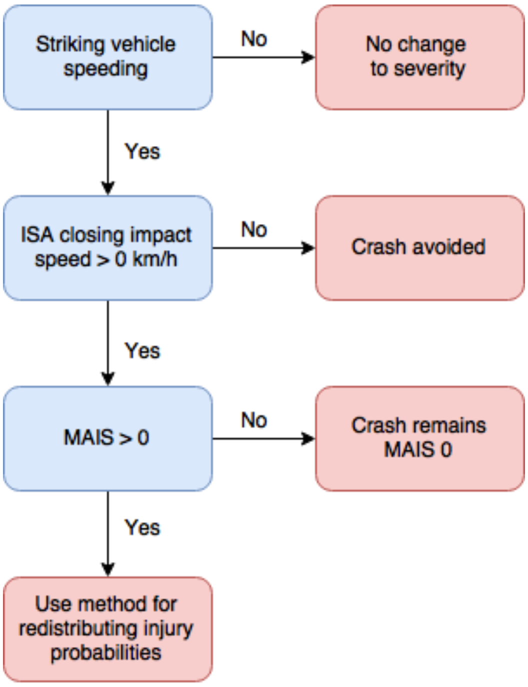

Figure 2.4
Flow diagram for estimating the potential crash injury reduction with limiting ISA

2.3.1 Vehicle speed and injury risk

Several studies have attempted to relate crash vehicle impact speed or delta-v to risk of occupant injury in the form of a delta-v – injury risk relationships. Many of these studies have predominantly focused on risk of serious injury (e.g. Augenstein, Perdeck, Stratton, Digges, & Bahouth, 2003). However, NHTSA (2005) derived individual probability risk functions for MAIS 0, MAIS 1+, MAIS 2+, MAIS 3+, MAIS4+, MAIS 5+ and fatal injuries. The NHTSA injury probability risk functions were chosen for the analyses as they were considered the most appropriate for the particular analysis considered here. Using the NHTSA delta-v – injury risk functions[1] for MAIS 0, MAIS 1 – 2 and MAIS 3+, risk curves were generated for these injury categories.

Figure 2.5 shows the absolute risk of a particular injury (relative to the other injuries), adapted from NHTSA (2005) for the three defined injury categories. This presentation of the risk curves considers the individual risks of MAIS 0, MAIS 1 & 2 and MAIS 3+ as a proportion of 100 per cent for increasing levels of delta-v[1].

Figure 2.5 shows that at a delta-v of 0 km/h the probability of a MAIS 0 injury (no injury) is 100 per cent, and zero for MAIS 1 or 2 and MAIS 3+ injury respectively. At a delta-v of 50 km/h the risk of an MAIS 0 is 8.1 per cent, the risk of MAIS 1 or 2 is 73.8 per cent, and the risk of an MAIS 3+ injury is 18 per cent, with the total risk of an injury or non-injury being 100% for any delta-v. The apportioning of injury risk can also be seen diagrammatically on the cumulative injury risk curves shown in Figure 2.6.

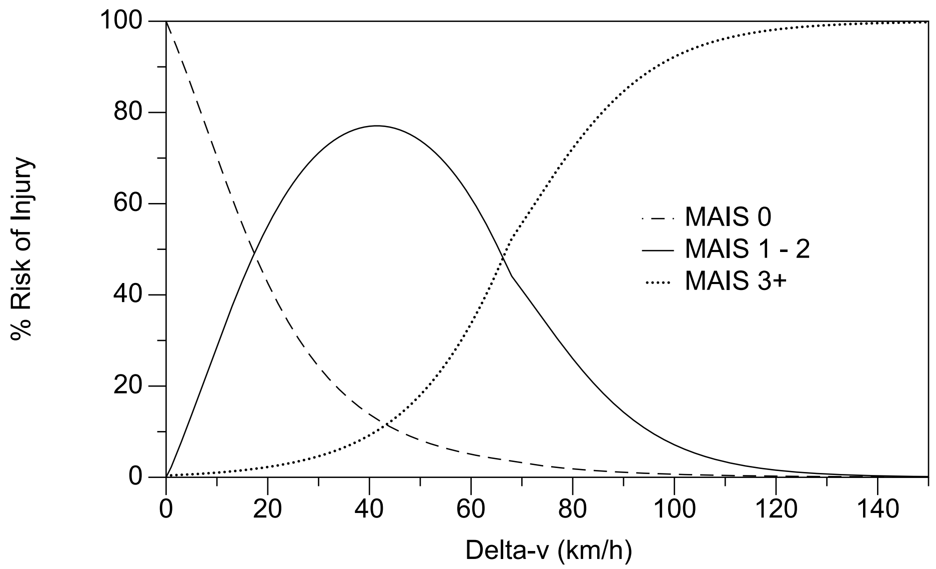

Figure 2.5
Maximum occupant injury risk curves adapted from
NHTSA (2005), for MAIS 0, MAIS 1-2 and MAIS 3+ injuries

[1] The risk functions derived in NHTSA (2005) assume the condition that occupants would sustain at least an MAIS 1+ injury at 36 mph (58 km/h) or greater and hence no MAIS 0 also above this delta-v threshold. This condition was not retained for the analysis in this study, as this would result in discontinuity in the MAIS 0 and MAIS 1 – 2 risk-curves. Hence the injury risk curves from NHTSA (2005) were slightly modified to reflect this. Additionally, the risk curve for MAIS 1 for delta-v greater than or equal to 68 km/h was assumed to be zero for MAIS 1 – 2 to maintain risk curve continuity.

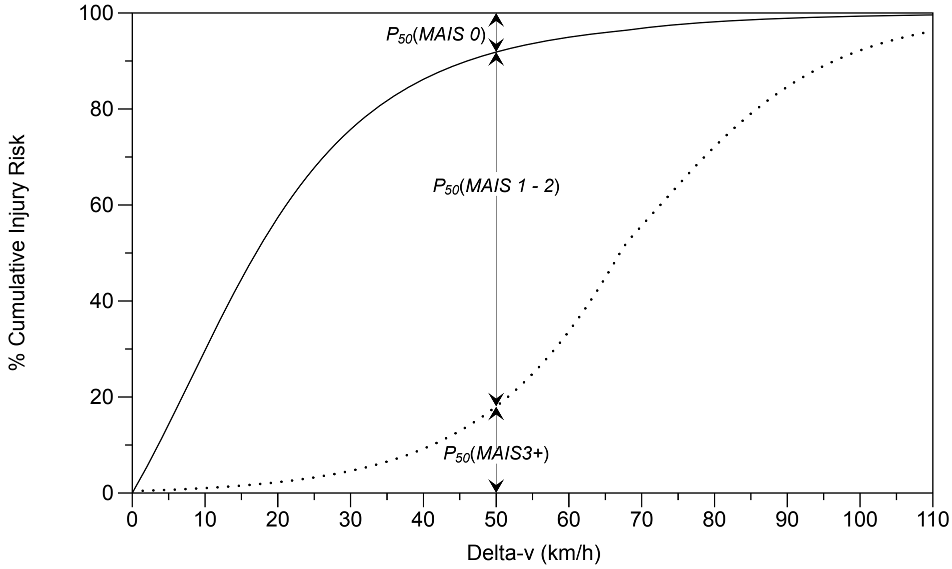

Figure 2.6
Cumulative occupant injury risk curves derived from NHTSA (2005), showing the injury risk proportion for MAIS 0, MAIS 1 - 2 and MAIS 3+ at each delta-v and shown schematically for delta-v of 50 km/h

Vehicle occupant injury risk is posed in terms of delta-v, as discussed previously. A general relationship between delta-v and closing speed was used to estimate the delta-v that would be produced in each relevant crash scenario.

From the CASR in-depth crash studies, the individual speed reconstructions yield a longitudinal closing speed and a corresponding delta-v. Considering a number of crash configurations and generalising, the relationships for delta-v and longitudinal closing speed were derived as shown in Table 2.3.

Table 2.3
Estimated relationship between longitudinal closing speed and delta-v for various crash configurations

CASR In-depth Crash Type	Delta-v Functions
Head-on collisions	Delta-v = 0.5 x closing speed
Hit fixed object	Delta-v = closing speed
Intersection	Delta-v = 0.6 x closing speed
Rear End	Delta-v = 0.6 x closing speed

2.3.2 Determining crash injury outcomes with ISA

The process for determining the effect of ISA on the crash injury proceeded using the following steps:

For the original crash, (without an ISA system):

- The actual crash closing speed for the vehicle, derived from the EDR impact speed was converted to a delta-v according to Table 2.3.
- The risk of MAIS 3+, MAIS 1-2 or MAIS 0 (no injury) was determined and apportioned from the appropriate risk functions in Figure 2.6.

To determine the effect of ISA on the crashed vehicle being assessed, the closing speed was calculated based on a speed limiting ISA system enforcing full speed limit compliance, and the resulting (if any), closing speed reduction. Correspondingly:

- The new delta-v was calculated according to Table 2.3 based on the new closing speed.
- The new risk of MAIS 3+, MAIS 1-2 or MAIS 0 (no injury) was determined from the appropriate risk functions in Figure 2.6 for the ISA modified delta-v.

To estimate the new injury risks, given an ISA system speed reduction, the crash injury severities were redistributed into new injury risk proportions at the original severity category or a lower category.

For a crash where the outcome was a moderate injury (MAIS1 - 2), the injury risks are determined by equations 4 and 5. The definitions for the variables used are shown in Table 2.4.

$$P_{ISA\ Speed}\ (MAIS\ 1-2|crash\ was\ MAIS\ 1-2) = \frac{1-P_{crash\ speed}(MAIS3+)-P_{ISA\ Speed}(MAIS\ 0)}{P_{crash\ speed}(MAIS\ 1-2)} \quad (4)$$

$$P_{ISA\ Speed}\ (MAIS\ 0|crash\ was\ MAIS\ 1-2) = 1 - P_{ISA\ Speed}\ (MAIS\ 1-2|crash\ was\ MAIS\ 1-2) \quad (5)$$

Table 2.4
Nomenclature for Equations

Risk Function Predictors	Crash Speed	ISA Speed
Probability of no injury	$P_{crash\ Speed}\ (MAIS\ 0)$	$P_{ISA\ Speed}\ (MAIS\ 0)$
Probability of moderate injury	$P_{crash\ Speed}\ (MAIS\ 1-2)$	$P_{ISA\ Speed}\ (MAIS\ 1-2)$
Probability of severe injury	$P_{crash\ Speed}\ (MAIS\ 3+)$	$P_{ISA\ Speed}\ (MAIS\ 3+)$

As an example, consider a scenario where an MAIS 1 - 2 injury resulted from a vehicle that crashed with a delta-v of 50 km/h. At a delta-v of 50 km/h the risk curves in Figure 2.5 give risks of injury in the crash. $P_{50}(\text{MAIS } 0)$ = 8.13 per cent, $P_{50}(\text{MAIS } 1-2)$ = 73.85 per cent and $P_{50}(\text{MAIS } 3+)$ = 18.01 per cent. These three injury risk proportions are depicted by the intervals in the injury areas of the curves shown in Figure 2.6. Now consider the effect of the ISA system that reduces the closing speed of the assessed vehicle and the corresponding delta-v of that vehicle to 18 km/h. The predicted injury risk distributions are shifted, as indicated in Figure 2.7, where $P_{18}(MAIS\ 0)$ = 47.43 per cent, $P_{18}(MAIS\ 1-2)$ = 50.63 per cent and $P_{18}(MAIS\ 3+)$ = 1.93 per cent. The new injuries are then redistributed according to equation 6 and 7, where only two injury outcomes are possible, based on the actual initial moderate injury sustained.

$$P_{18}(mod|crash\ was\ mod) = \frac{1-P_{50}(MAIS3+)-P_{18}(MAIS\ 0)}{P_{50}(MAIS\ 1-2)} = \frac{1-0.08-0.47}{0.74} = 47\% \quad (6)$$

$$P_{18}(no\ inj\ |crash\ was\ mod) = 1 - P_{18}(mod|crash\ was\ mod) = 1 - 0.47 = 53\% \quad (7)$$

where

mod = moderate injury
no inj = no injury

As a result, the moderate injury sustained in the original crash has been redistributed to 0.47 moderate injuries and 0.53 no injuries, this is shown diagrammatically in Figure 2.8.

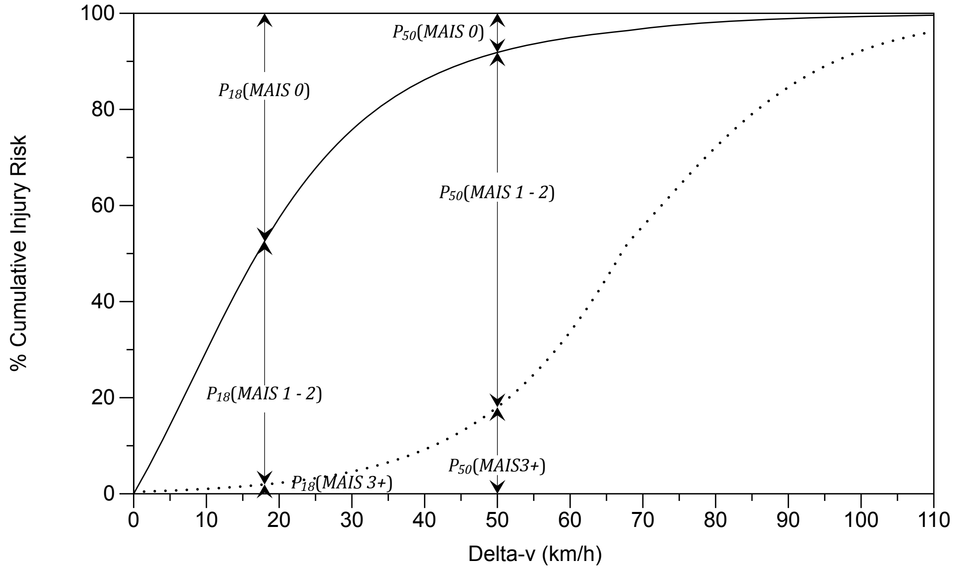

Figure 2.7
The injury risks at a delta-v of 50 km/h and 18 km/h

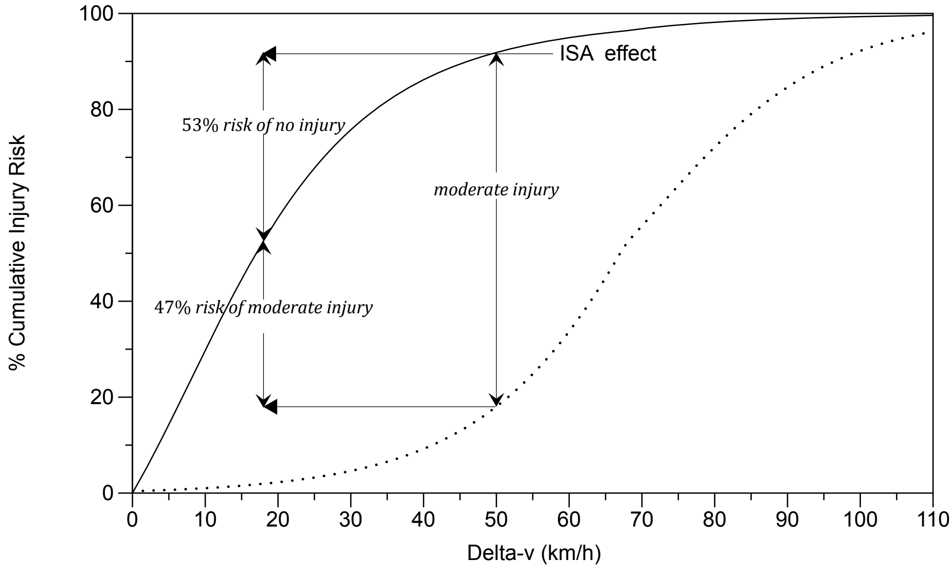

Figure 2.8
An example of the re-distribution of an injury from a delta-v of 50 km/h to a delta-v of 18 km/h

In the case of a severe injury crash, the severity is also redistributed based on the predicted injury risks (at the original crash delta-v and the ISA reduced delta-v) and the serious injury risk is re-distributed into risk of serious injury and risk of moderate injury outcomes according to equation 8 and 9.

$$P_{ISA\ Speed}\ (severe|crash\ was\ severe) = \frac{P_{ISA\ Speed}(MAIS\ 3+)}{P_{crash\ speed}(MAIS\ 3+)} \quad (8)$$

$$P_{ISA\ Speed}\ (mod|crash\ was\ severe) = \frac{P_{crash\ speed}(MAIS\ 3+) - P_{ISA\ Speed}(MAIS\ 3+)}{P_{crash\ speed}(MAIS\ 3+)} \quad (9)$$

where

severe = severe injury
mod = moderate injury

Consider a scenario where a serious injury resulted from a vehicle that crashed with a delta-v of 78 km/h. Figure 2.9 shows the no injury, moderate injury and serious injury predicted distributions at 78 km/h. At a delta-v of 78 km/h, the serious injury risk (MAIS 3+) according to Figure 2.5 is 69.07 per cent. This 69.07 per cent serious injury risk is depicted by the $P_{78}(MAIS\ 3+)$ interval in the MAIS 3+ injury area of Figure 2.9. The corresponding values for $P_{78}(MAIS\ 1-2)$ and $P_{78}(MAIS\ 0)$ being 28.89 per cent and 2.04 per cent respectively. The effect of an ISA system that reduces the delta-v to 56.4 km/h is that the injury risks are shifted as indicated in Figure 2.9, to 26.43 per cent, 67.51 per cent and 6.06 per cent for $P_{56.4}(MAIS\ 3+)$, $P_{56.4}(MAIS\ 1-2)$ and $P_{56.4}(MAIS\ 0)$ respectively. The serious injury is redistributed according to equation 8 and 9 and shown schematically in Figure 2.10.

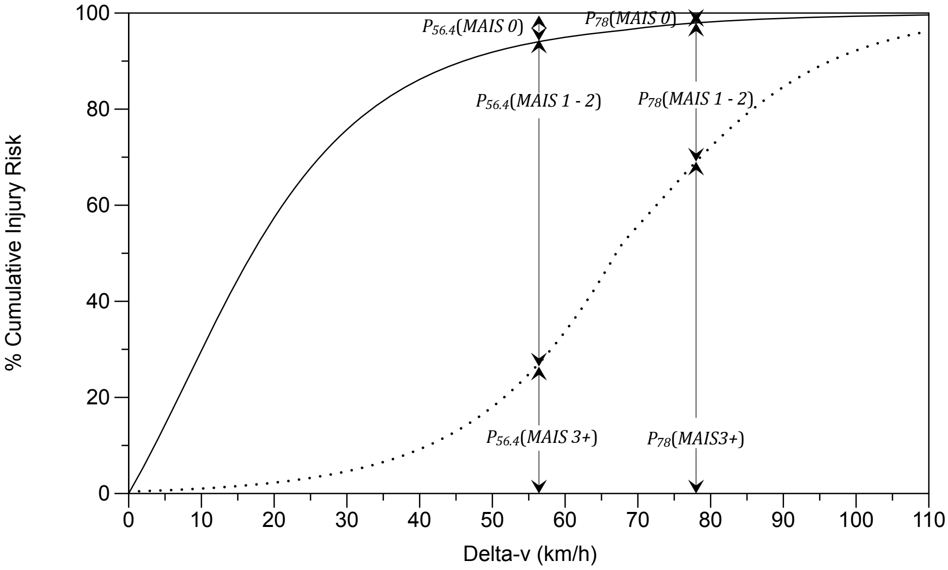

Figure 2.9
The injury risks at a delta-v of 78 km/h and 56.4 km/h

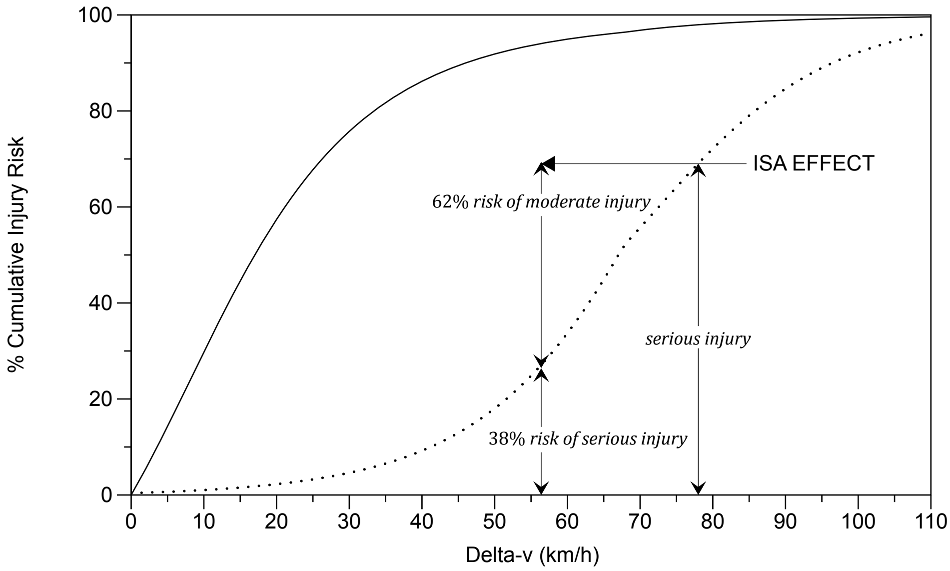

Figure 2.10
An example of the redistribution of a serious injury from a delta-v of 78 km/h to an ISA reduced delta-v of 56.4 km/h

Then according to equation 8 and equation 9.

$$P_{56.4}(serious|crash\ was\ serious) = \frac{P_{56.4}(MAIS\ 3+)}{P_{78}(MAIS\ 3+)} = \frac{0.264}{0.691} = 38\%$$

$$P_{56.4}(mod|crash\ was\ serious) = \frac{P_{78}(MAIS\ 3+) - P_{56.4}(MAIS\ 3+)}{P_{78}(MAIS\ 3+)} = \frac{0.691 - 0.264}{0.691} = 62\%$$

where

serious = serious injury
mod = moderate injury

The risk re-distribution results in the original serious injury being redistributed as 0.38 serious injuries and 0.62 moderate injuries for the above scenario.

In some cases a serious injury is redistributed as a serious injury, moderate injury and no injury, this occurs when:

$$P_{ISA\ Speed}\ (no\ inj) > 1 - P_{crash\ speed}(serious)$$

In this case equation 10 replaces equation 8 and equation 11 is used to calculate the probability of no injury.

$$P_{ISA\ Speed}\ (mod|crash\ was\ serious) = \frac{P_{ISA\ Speed}\ (mod)}{P_{crash\ speed}(serious)} \qquad (10)$$

$$P_{ISA\ Speed}\ (no\ inj|crash\ was\ serious) = \frac{P_{crash\ speed}(serious) - P_{ISA\ Speed}(serious) - P_{ISA\ Speed}\ (mod)}{P_{crash\ speed}(serious)} \qquad (11)$$

where

serious = serious injury
mod = moderate injury
no inj = no injury

The above processes were applied to each individual crash in the sample where a limiting ISA system would have been able to reduce the delta-v. The estimated individual probability outcomes for each crash were then summed across all crashes to give the estimated number of injury crashes with a limiting ISA system fitted to all vehicles.

3 Results

The results of this pilot study are presented below. The overall result should be viewed as preliminary due to the small sample analysed. Results for different subgroups should be treated with further caution and are given only as an indication of the type of analysis that could be conducted with a larger sample.

3.1 Speeds and speeding within the sample

The speed limit for the striking vehicles by the vehicles speeding status is shown in Table 3.1. The most common speed limit was 56 km/h (35 mph) and the majority of the speed limits were between 40 km/h (25 mph) and 72 km/h (45 mph). The levels of speeding in the sample were high, with more than half the vehicles travelling above the speed limit (61%). The speed limit did not appear to have any relationship to the level of speeding, though this could be purely a result of the small sample size.

Table 3.1
Speed limits and speeding for the sample of NASS-CDS crashes

Speed limit km/h (mph)	Total	Not speeding		Speeding	
	Number	Number	Percentage	Number	Percentage
32.2 (20)	1	0	0%	1	100%
40.25 (25)	7	4	57%	3	43%
48.3 (30	5	1	20%	4	80%
56.35 (35)	19	6	32%	13	68%
64.4 (40)	10	4	40%	6	60%
72.45 (45)	10	5	50%	5	50%
80.5 (50)	2	0	0%	2	100%
88.55 (55)	2	1	50%	1	50%
104.65 (65)	2	2	100%	0	0%
112.7 (70)	1	0	0%	1	100%
Total	59	23	39%	36	61%

Table 3.2 shows the mean and median travel speed relative to the speed limit of the striking vehicle by injury severity. Only the non-injury crashes were, on average, travelling below the speed limit. Serious injury crashes had an average speed well above the speed limit. This suggests that limiting ISA will be most effective at reducing serious injuries.

Table 3.2
Travel speed relative to speed limit by injury severity for the sample of NASS-CDS crashes

Travel speed relative to speed limit	MAIS (Injury severity)		
	0 (Non-injury)	1-2 (Moderate)	3+ (serious injury)
Mean	-6.8	7.1	20.1
Median	-8.4	5.4	19.2

3.2 Injury reduction

The potential injury reductions due to limiting ISA for the sample of NASS-CDS crashes are shown in Table 3.3. ISA was found to have the greatest effect for serious injury crashes, reducing these crashes by over 62%. Moderate injury crashes were also reduced substantially (27%). Of particular note is that 13 of the 59 crashes (22%) would have been avoided altogether. The rise in non-injury crashes is a result of a proportion of the injury crashes still resulting in impacts, but at speeds that are unlikely to be injurious. The reduction in minor and moderate injury crashes is tempered by similar transference from serious injury crashes.

Table 3.3
Estimated outcomes of limiting ISA on the sample of NASS-CDS crashes

Injury Severity	Without ISA	With ISA	Change
MAIS 3+	8	3.02	-62.2%
MAIS 1,2	40	29.11	-27.2%
MAIS 0	11	13.86	26.0%
No crash	0	13.00	-
Total	59	59	-

Tables 3.4 and 3.5 show examples of the type of analysis that could be conducted with a larger sample size. The sample size is insufficient to place much importance on the results for each crash type; however, it is encouraging that the general pattern is found across all crash types. The results shown in Table 3.5 follow what would be expected: that the benefit of ISA increases as the level of speeding increases.

Table 3.4
Estimated outcomes of limiting ISA on the sample of NASS-CDS crashes by crash type and severity

Crash type	Crash severity									
	MAIS 3+ (Serious injury)			MAIS 1,2 (Moderate injury)			MAIS 0 (Non-injury)			No crash with ISA
	Without ISA	With ISA	Change	Without ISA	With ISA	Change	Without ISA	With ISA	Change	
Right angle	3	1.42	-52.7%	7	6.21	-11.3%	3	2.37	-21.0%	-52.7%
Right turn - adjacent	0	0.00	NA	3	1.01	-66.2%	1	1.99	98.6%	NA
Right turn - opposing	1	0.00	-100.0%	6	3.76	-37.3%	1	3.24	224.0%	-100.0%
Rear end	0	0.00	NA	5	4.33	-13.4%	3	3.67	22.3%	NA
Head on	1	0.77	-23.0%	4	3.69	-7.7%	1	1.54	53.8%	-23.0%
Hit fixed object	3	0.83	-72.2%	14	10.11	-27.8%	2	1.06	-47.1%	-72.2%
Other	0	0.00	NA	1	0.00	-100.0%	0	0.00	NA	NA
Total	8	3.02	-62.2%	40	29.11	-27.2%	11	13.86	26.0%	-62.2%

Table 3.5
Estimated outcomes of limiting ISA on the sample of NASS-CDS crashes by level of speeding and severity

Level of speeding (km/h)	Crash severity									No crash with ISA
	MAIS 3+ (Serious injury)			MAIS 1,2 (Moderate injury)			MAIS 0 (Non-injury)			
	Without ISA	With ISA	Change	Without ISA	With ISA	Change	Without ISA	With ISA	Change	
0.1 - 9.9	0	0.00	-	11	9.09	-17.4%	0	1.91	NA	0
10 - 19.9	3	1.15	-61.6%	4	1.61	-59.6%	3	2.23	-25.5%	5
20+	4	0.87	-78.2%	11	4.41	-59.9%	0	1.72	NA	8

4 Discussion

4.1 Discussion of results

The overall results of this pilot study into limiting ISA are encouraging: over 20% of crashes avoided completely, a high percentage reduction for serious injury crashes (62%), and a substantial reduction in minor and moderate injury crashes (27%). Non-injury crashes were estimated to increase by 26% due to injury crashes that could not be completely avoided. An analysis of a much larger sample size should be performed to produce a more robust result.

The effect of limiting ISA will be dependant upon the percentage of drivers that travel over the speed limit, and to what degree they travel over the speed limit. For this reason the results based on data from one jurisdiction cannot be applied to another jurisdiction without considering the differences in speeding behaviour between the two. For example, 61% of drivers in the NASS-CDS sample taken from the USA were travelling above the speed limit. This appears to be much higher than speeding levels in Australia. Doecke and Kloeden (2014) found that 27% of striking vehicles were travelling faster than the speed limit in crashes reconstructed as part of CASR's in-depth crash investigations. Kloeden and Woolley (2015) found that between 12 and 43% of vehicles were travelling above the speed limit, depending on the type of road, at 130 sites around South Australia. Holman (n.d.) found that in rural 110 km/h zones and metropolitan 60 km/h zones in Western Australia, 25% and 47% respectively were travelling above the speed limit during 2009. This suggests that the effect of limiting ISA in Australia would therefore be less than in the USA. Care should be taken when generalising the results that the speeding behaviour differences have been taken into consideration.

Despite the high level of speeding in the sample, the results are relatively similar to the few previous studies that have calculated the reduction in crashes due to limiting ISA. The ISA UK-ISA project combined the results of their on-road trial with Kloeden's risk curves (Kloeden *et al.*, 1997; Kloeden *et al.*, 2001) and found that limiting ISA could reduce the number of injury crashes by 29% (Lai, Carsten & Tate, 2012). When the speed reductions achieved in the ISA-UK trial were applied to South Australian speed distributions (Doecke, Anderson & Woolley, 2010) a similar percentage reduction was found (26%). The studies that produced Kloeden's risk curves also found that if all vehicles were travelling at the speed limit injury crashes could be reduced by 46% on low speed urban roads (Kloeden *et al.*, 1997) and 24% on high speed rural roads (Kloeden *et al.*, 2001). The results of this pilot study for minor and moderate injury crashes are similar to those found in previous studies, though the serious injury reduction is much higher. This could be a product of the small sample size (only 8 serious injury crashes) and the high level of speeding found in the sample. A larger sample size will produce more robust overall results, particularly for serious injuries, and allow proper comparison with previous studies.

4.2 Discussion of EDR data

Part of the purpose of this pilot study was to explore the use of EDR data in answering research questions pertaining to vehicle technologies that reduce speed. In discussing EDR data as a whole, it must be acknowledged that EDR data differs greatly between vehicle manufacturers and time periods in terms of: scope, recording duration and recording frequency. The use of EDR data is discussed with reference and comparison to crash reconstruction, formally the exclusive method of obtaining travel speeds and impacts speeds of vehicles.

When considering a data source for a research topic the first consideration must be of completeness; does the data source contain all the required data? The majority of EDR files did contain the necessary data for this specific research topic: travel speed, impact speed, and braking TTC. However, there remained a considerable proportion that did not contain sufficient speed data. This lack of speed data can be attributed to the age of the vehicle for certain manufacturers, and will therefore become less prevalent with time, but for others it is an inherent limitation of how their EDR records data for multiple sensors. One of the great strengths of EDR data is information on brake use by the driver, and the resultant change in speed immediately prior to an impact. This allows travel speed and braking TTC to be determined. Crash reconstruction relies on tyre marks to calculate a precise travel speed and braking TTC. If the vehicle underwent braking for a period of time without locking its wheels, or the wheels did not lock due to ABS (a very common feature now) a crash reconstruction will produce an underestimate of travel speed, if it can be calculated at all. Crash reconstruction would also be unable to determine a braking TTC in these circumstances. In this way EDR data can produce a more complete and accurate dataset for research that relies on travel speed, impact speed and braking TTC.

The second consideration when selecting a data source is that of accuracy; how accurate is the data, and will we know when it is inaccurate? As mentioned in the method, the speed that is logged by the EDR comes from either wheel speed sensors or sensors that measure the rotation of the drive shaft. These sensors are also used to display the speed of the vehicle to the driver via the speedometer. No US Federal regulation for speedometer accuracy exists for light vehicles, but manufacturers are thought to voluntarily comply to the SAE recommended practice (Society of Automotive Engineers, 2011) of either ±2% of the maximum speed on the speedometer, or a bias towards over-reading on a sliding scale from -1.2 to +2.8% at 30 km/h to +4% at 90 km/h, still expressed as a percentage of maximum displayed speed. It is the authors understanding (based on personal conversations with industry contacts) that, in practice, speedometers are far more accurate than the tolerances given by the SAE, in recommended practice. In any case, if limiting ISA were to become a reality it should be tuned to the speed displayed by the speedometer so as not to increase travel speeds, as was done in the New South Wales advisory ISA trial (Doecke, Kloeden and Woolley, n.d.). In comparison, the accuracy of reconstructions in determining speed is difficult to ascertain. It is likely that accuracy will vary greatly due to factors such as the skill of the reconstructionist, the accuracy of the methods / computer programs being used, the type of crash, and the quality of the scene and vehicle evidence.

An important element of accuracy is being able to ascertain when the data is inaccurate, and must be rejected. The speed sensors of a vehicle will be inaccurate when the wheels are rotating at a speed significantly less than the speed of the vehicle through sideslip or braking. Under rotation due to braking can be determined by calculating the average acceleration between data points and checking for values that are beyond the capability of a road car (around 1g). Under rotation due to side slip may be more difficult to determine from the speed data as it may not necessarily exceed the 1g limit found for braking. If the scene has not been examined it may be possible to determine significant sideslip in the following ways; comparing EDR data on lateral acceleration to maximum values (only some EDRs), the vehicle's speed is reducing significantly without brake application, the vehicle struck an object with the side of the vehicle, or the police description stated the vehicle lost control. Altering the radius of the tyres through fitting non-standard rims and/or tyres will cause an error in the speed measurement. Though rare, this can be noted when examining the vehicle. It is difficult to determine when a reconstruction has produced inaccurate speeds, besides basic common sense tests. Many reconstructionists give a margin of error based on using upper and lower bounds for assumed values within their calculations, or even simply a degree of confidence in their result based on how well they can match the evidence. Neither of these methods guarantees that the speeds determined by the reconstruction are accurate. Inaccuracies can be more confidently identified in EDR data than in reconstruction data.

One of the greatest advantages of EDR data is that it requires far less effort to produce than traditional crash reconstruction. While there are varied methods of crash reconstruction (trajectory analysis, momentum analysis, damage analysis, combinations of the former) and computer programs to assist in the process (HVE, PC-CRASH, SMAC, FX, CRASH3 etc.) all require detailed forensic measurement of crash scene evidence and vehicle(s) in order to estimate speed (noting that damage analysis alone can only determine delta-V, not speed). The collection of such data represents a considerable investment of time, often in the order of 3-6 man-hours, depending on the amount of scene evidence and the proximity of the scene to the researchers base of operations. The processing of this data into a scaled drawing and the reconstruction itself could represent a further 2-6 man-hours. In contrast, downloading EDR data takes around 10 minutes in addition to the time taken to travel to the location of the crashed vehicle. EDR data therefore represents a considerable increase in the efficiency of data collection on speeds of vehicles in crashes.

4.2.1 Limitations of EDR data

The innovative use of speed and braking data from EDR files to examine pre-crash scenarios introduces certain limitations and biases into the sample.

Suitable EDR data is limited to certain makes, models, and model years of vehicles. This limitation does not apply to the struck vehicle, from which EDR data is usually not required. In the USA there are 38 currently sold makes of vehicles that are supported by the industry standard Bosch CDR tool for downloading from EDRs, with most major brands represented. However, there is much variation in the model years that are available. A number of vehicle makes only have EDR data available for recent models, while others date back to as early as the 1994 model year (Chevrolet). The sample is therefore likely to be bias towards newer vehicles. Furthermore, not all the EDR data contains the information that is required. As mentioned earlier in the Method Section, General Motors' vehicles did not contain suitable information, and the first generation Toyota EDRs did not record speed. The effect of this limitation on the level of speeding in the sample, and therefore on the results, is unclear. One possibility is that young drivers may be under-represented in the sample as they may be less likely to purchase a newer vehicle. This may have some bearing on the level of speeding and injuries in the sample. Driver demographics could be investigated in future studies to confirm or discount this. The vehicle makes and model years could also be recorded to quantify this aspect of the sample.

EDR data alone was unsuitable for certain crash configurations. In most instances EDR data was only available from one vehicle involved in the crash. This resulted in the exclusion of rear end and head on crashes where the impact speed, and hence the closing speed, of both vehicles could not be determined. For head on crashes it may be possible to determine the impact speed of the non-EDR equipped vehicle, though the effort involved may approach that of a full reconstruction. Crashes where the striking vehicle lost control prior to impact and developed a significant sideslip angle were excluded on the grounds that the EDR speed data does not reflect the true speed of the vehicle. The reconstruction effort to determine the travel and impact speed of these vehicles may be much smaller than a full reconstruction, though the ability to do so would depend upon sufficient tyre marks being accurately recorded to determine the sideslip angle of the vehicle at the point at which travel speed and impact speed are calculated. Crashes with a low delta-V may not be recorded by the

EDR. This is particularly a problem for crashes with pedestrians or bicycles where a low delta-V for the vehicle does not correspond to a minor crash.

4.3 The NASS-CDS database

The NASS-CDS database is a valuable source of EDR data, however, it has several limitations. The largest limitation is the lack of data on vehicles more than nine years old, and their occupants. This means that any analysis using NASS-CDS that considers injury is only reflective of a subset of the fleet that has an average age of around 5-6 years old. The average age of a vehicle in Australia is 10.1 years (Australian Bureau of Statistics, 2016) and the age of crashed vehicles is older still (Anderson & Doecke, 2010). Such an analysis of NASS-CDS data could be thought of as reflecting a future situation. For example, as the data for this pilot study was taken from 2013, the average year of manufacture of the vehicles is probably around 2007-2008. Crashed vehicles would have a similar average year of manufacture in 2018.

A further limitation of the NASS-CDS database is that it only includes crashes between light vehicles. ISA has the potential to reduce the impact speed in crashes with vulnerable road users. This can not be explored with NASS-CDS data, though EDR data may not be suitable for low mass vulnerable road users in any case.

4.4 Injury estimation

The injury risk curves derived from NHTSA (2005) were the most suitable curves available for this study, as they provide injury risk estimates for each level of MAIS and fatal. The NHTSA (2005) injury risk curves are based on 1995-1999 NASS-CDS data for all occupants involved in passenger vehicle crashes, where at least one crashed vehicle had applied their brakes. The crash data obtained for analysis in this study is much newer, being extracted from NASS-CDS for crashes that occurred in 2013. With improved vehicle crashworthiness, it is most likely that injury risk curves used in this study may be overestimating risk for the vehicles included in the sample. Using the actual injury to scale and re-assign injury risk may temper the impact that this may have on the result.

The risk curves used refer to a vehicle-based measure of severity, whereas we have used them to indicate severity in a crash. Theoretically, it might be appropriate to adjust the risk curves accordingly. The more units involved in a crash, the greater the likelihood that the severity will be higher due to random effects. However, no adjustment was made on the following grounds:

- In at least half of injury crashes and in the majority of fatal 2-car crashes, the outcome is asymmetrical and a single unit determines the severity. No adjustment is necessary in these cases.

- Adjusting the risk curves would have inflated the risks in multi-unit crashes. Given the curves are based on injury outcomes in much older vehicles (circa 1990), we felt that any adjustment that would inflate the risks would be over-stating risks in a future fleet of vehicles.

5 Conclusions and recommendations

The following conclusions can be drawn from this pilot study on limiting ISA that used EDR data from the NASS-CDS database:

- Limiting ISA may have the potential to produce large reductions in injuries, particularly serious injuries.
- The large benefits found in this study may be smaller in jurisdictions with superior speed compliance.
- The NASS-CDS database is a large source of EDR data but limits the analysis to crashes involving light vehicles that are less than ten years old.
- Less than 10% of EDR files within the NASS-CDS database are suitable and this can result in a large amount of time being spent simply identifying suitable crashes. Methods to reduce this time would be worthwhile for a larger sample.
- The EDR data that is suitable appears to be more accurate and complete than data from reconstruction.
- Use of EDR data can restrict the crash types and vehicle types in the sample.

These conclusions lead to the following recommendations:

- A study with a larger sample should be undertaken to provide a more robust result.
- This study should use EDR data from the NASS-CDS database.
- Methods to reduce the time taken to identify suitable crashes within the NASS-CDS database should be developed.
- The feasibility of an Australian EDR database matched to injury data should be investigated.

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