Centre for Automotive Safety Research

Preventing and mitigating truck crashes: results from 100 in-depth no-blame truck crash investigations

CASR216

SD Doecke, ME Elsegood, JP Thompson, G Ponte, SA Edwards & S O'Donovan

Report documentation

REPORT NO.	DATE	PAGES	ISBN	ISSN
CASR216	January 2024	69	978 1 925971 50 7	1449-2237

Title

Preventing and mitigating truck crashes: results from 100 in-depth no-blame truck crash investigations

Authors

SD Doecke, ME Elsegood, JP Thompson, G Ponte, SA Edwards & S O'Donovan

Performing Organisation

Centre for Automotive Safety Research
The University of Adelaide
South Australia 5005
AUSTRALIA

Funding

This project was funded by the Australian Government and administered by the Office of Road Safety, via the Road Safety Innovation Fund

Available From

Centre for Automotive Safety Research; http://casr.adelaide.edu.au/publications/list

Abstract

Trucks play an important role in the Australian economy but also make a substantial contribution to the lives lost on Australian roads. The aim of the present study was to undertake a substantial sample (n=100) of in-depth no-blame crash investigations of crashes involving trucks to identify the factors that contribute to their occurrence, and the interventions that show the most potential to prevent such crashes or mitigate the resulting injuries. Truck crashes were investigated within 200 km of Adelaide, South Australia, and mostly occurred in the city and inner regional areas. The sample was biased towards more severe crashes. While human factors were the most common contributor to truck crashes, road and vehicle-based interventions were found to have the greatest potential to prevent and mitigate truck crashes. Road-based interventions aimed at preventing and mitigating crashes at intersections were found to be particularly important for truck crashes. These interventions include roundabouts, the installation of traffic lights (with fully controlled right turns), grade separating intersections, preventing right turns, vertical deflection, and improving the geometry of the intersection. The truck technologies found to have the most potential for crash prevention and mitigation were electronic stability control (ESC) and autonomous emergency braking (AEB). The reduction of speed limits and the installation of centre barriers were also found to be important interventions to mitigate injuries from crashes involving trucks. The maximum benefit can be achieved from these interventions if a system-wide approach is taken to their introduction.

Keywords

Truck, Crash, Crash prevention, Crash mitigation, Roundabout, ESC, AEB, Centre barrier

Summary

Trucks play an important role in the Australian economy by transporting goods throughout the country. However, crashes that involve trucks also make a substantial contribution to the number of people killed on Australian roads. Crashes involving trucks are more likely to result in serious injury or death. The purpose of conducting in-depth no-blame crash investigations is to understand a crash in as much detail as possible. Investigations of this type identify the factors that contribute to crashes occurring, as well as the interventions that could prevent the crashes or mitigate any resulting injuries. The aim of the present study was to undertake a substantial sample (n=100) of in-depth no-blame investigations of crashes involving trucks.

The 100 crashes involving trucks that were investigated for this report came from two distinct time periods, in which slightly different methods were used. There were 32 pre-existing investigations of crashes involving trucks that were conducted between October 2014 and June 2021 as part of ongoing CASR in-depth crash investigation activities. These were casualty crashes (in which at least one participant was transported by ambulance to hospital) investigated within 100 km of Adelaide. A further 68 crashes involving trucks were investigated between July 2021 and February 2023 to reach the target sample of 100 crashes. The investigation area was extended to 200 km for these crashes and non-injury rollover and high-speed-zone (100 km/h+) crashes were included. The investigations involved collecting a wide range of information on the crash, both at the scene of the crash and afterwards, and detailed analysis and review of this information.

Human factors were found to have contributed to the most truck crashes, consistent with prior studies using similar methods to study road crashes in general. Common contributing factors included speed, both too high for conditions and exceeding the limit, and human errors associated with failing to give way at an intersection. However, vehicle factors were found to have contributed to a larger proportion of the truck crashes than a prior study not focussed on trucks that was conducted within a similar geographic area and with a similar methodology. The most frequent vehicle-related contributing factor was the dynamic stability of the truck, followed by truck blind spots.

While human factors contributed to the most truck crashes, road and vehicle-based interventions were found to have the greatest potential to prevent and mitigate truck crashes. Road-based interventions aimed at preventing and mitigating crashes at intersections were found to be particularly important for truck crashes. These interventions include roundabouts, the installation of traffic lights (with fully controlled right turns), grade separating intersections, preventing right turns, vertical deflection, and improving the geometry of the intersection. The truck technologies that were found to have the most potential for crash prevention and mitigation were electronic stability control (and the associated trailer roll stability systems) and autonomous emergency braking. The reduction of speed limits and the installation of centre barriers were also found to be important interventions to mitigate injuries from crashes involving trucks.

The maximum benefit can be achieved from these interventions if a system-wide approach is taken. For road-based interventions, this means proactive widespread application of interventions rather than reactive installation at individual locations. For vehicle technologies, this means encouraging rapid take-up through a combination of regulation, incentives, and consumer rating schemes.

Table of Contents

1. Introduction

Trucks play an important role in the Australian economy by transporting goods throughout the country. The Bureau of Infrastructure, Transport and Research Economics (BITRE) reported that in the 2015-16 financial year, road freight had reached 203 billion tonne kilometres, accounting for 28% of the Australian freight task. Road freight was projected to reach 280 billion tonne kilometres by 2030, representing 35% of the national freight task (Bureau of Infrastructure, Transport and Regional Economics, 2019). However, trucks also make a substantial contribution to an undesirable statistic, the number of people killed on Australian roads.

1.1. Truck crashes by the numbers

Figure 1.1 presents data from a BITRE (2023) report on the number of deaths from crashes involving a heavy truck between 2012 and 2021, and these deaths as a percentage of deaths from all road crashes. A heavy truck is defined as having a gross vehicle mass (GVM) of greater than 4.5 tonnes. There are no national statistics reported for light trucks (GVM less than 4.5 tonnes). In 2021, there were 163 deaths from crashes involving heavy trucks, representing 15% of all deaths from road crashes. Over the ten years (2012-2021), there were 1,881 deaths from crashes involving heavy trucks. While there does appear to be somewhat of a downward trend in these figures, a considerable number of deaths from crashes involving heavy trucks continue to occur each year.

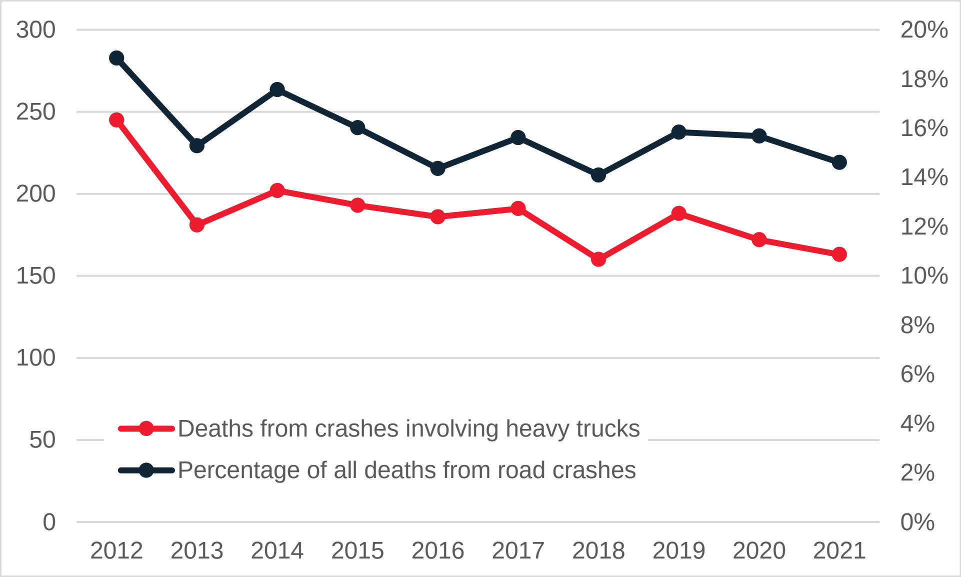


Figure 1.1
Deaths from crashes involving heavy trucks in Australia
(Source: Bureau of Infrastructure, Transport and Regional Economics, 2023)

Truck crashes tend to result in a higher level of injury severity than crashes involving only light vehicles. The Traffic Accident Reporting System (TARS) in South Australia contains records of police-reported crashes. TARS data for injury crashes occurring between 2014 and 2022 (inclusive) revealed crashes involving trucks were much more likely to be fatal, and slightly more likely to result in a hospital admission (Figure 1.2). This is consistent with Budd, Newstead and Watson (2021), who found that serious injury risk to collision partners in heavy vehicle crashes is between two to four times higher than if the collision partner were a light vehicle.

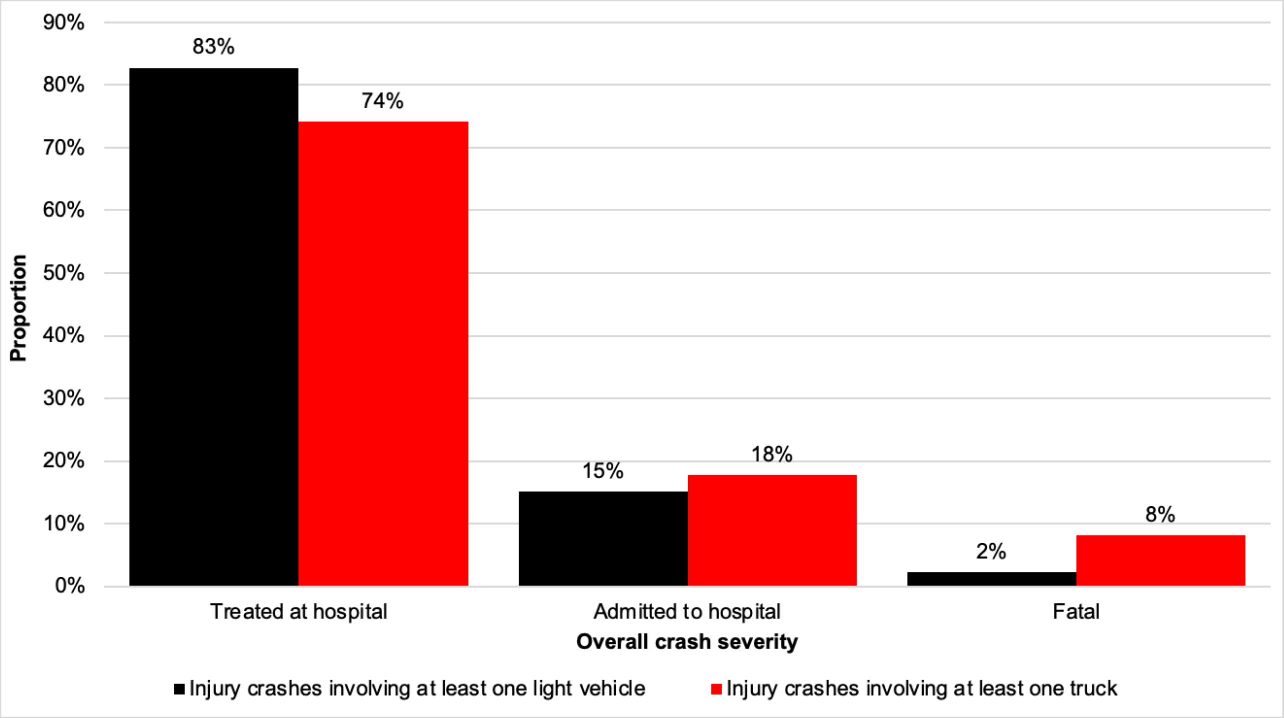


Figure 1.2
Proportion of TARS car-only crashes vs TARS truck-involved crashes by overall crash injury severity (2014-2022)

1.2. The theory of truck crash severity

There are several theoretical reasons why crashes involving trucks would be expected to have a higher probability of death or serious injury than the equivalent crash that does not involve a truck. Perhaps the most obvious of these reasons is the mass of the truck. Many trucks will weigh at least 10 times as much as a car, and with some of the large combinations permitted in Australia, could weigh more than 100 times as much as a car. In a collision between a truck and a car, the difference in mass leads to a significantly greater change in velocity (delta-*v*) for the occupants of the car, compared to a scenario in which the masses are similar, and delta-v is positively related to risk of serious injury. (Bahouth, Digges & Schulman, 2012; Bahouth *et al.,* 2014; Brumbelow, 2019).

The mass of trucks also has a theoretical influence on the risk of serious injury in collisions with fixed objects. When a vehicle collides with a fixed object much of its kinetic energy is translated to work done on the vehicle structure, also known as deformation. As kinetic energy is directly proportional to mass, a truck moving at a given speed has much more kinetic energy than a light vehicle moving at the same speed. In a collision with a fixed object this can result in much more deformation, and ultimately occupant compartment intrusion, to vehicles with a large mass (such as a truck) compared to a light vehicle, though it is also dependent on vehicle stiffness.

Stiffness and compatibility are other theoretical reasons why crashes involving trucks have a higher probability of serious injury or death. Many parts of the structure of a truck have a much higher stiffness than the equivalent area on a car. This higher stiffness can lead to greater deformation to a collision partner with a lower stiffness, such as a light vehicle, and higher accelerations being experienced by the occupants of both vehicles. Compatibility, in the context of a vehicle crash, refers to how well the crash protection structures of the vehicles engage with each other so that the occupants are protected (Krusper & Thomson, 2008). Compatibility between a truck and a car may, theoretically, be much less than between a car and another car, as the design of crash structures is often driven by passing or scoring well in crash tests (regulatory or consumer) which are aimed at replicating car-to-car collisions. The higher stiffness of truck structures and potential collision incompatibility between trucks and light vehicles could contribute to an increased risk of serious injury or fatality in crashes involving trucks.

1.3. The theory of no-blame in-depth investigations

The purpose of in-depth no-blame crash investigations is to understand a crash in as much detail as possible so that contributing factors can be identified and conclusions can be drawn on how the crash could have been prevented or mitigated. That such investigations are referred to as “in-depth” signifies the extensive amount of information gathered, and the high level of analysis involved. An early pioneer of in-depth crash investigations of road crashes in Australia, Jack McLean, referred to the role of in-depth investigations as being “to provide essential information that cannot be obtained in any other way” (McLean, 1973). Consequently, these in-depth crash investigations go beyond mere data matching exercises, as they entail the collection and generation of new data throughout the process. Moreover, they involve what Segal (1970) described as a “first-hand look at the problem”. This “first-hand look” is best achieved when investigators promptly attend the crash scene, ideally when the vehicles are still in their final positions and the evidence is fresh and uncontaminated.

The designation of these investigations as “no-blame” underscores their independence. A no-blame investigation can only be conducted by a group that is truly independent of any other group that has an interest in determining liability and / or taking criminal, regulatory, or administrative action. The “no-blame” aspect of in-depth crash investigation aims to encourage individuals who might otherwise seek to avoid blame, and the resulting consequences, to share information openly and honestly with the investigators. In this sense, “no-blame” investigations may be able to provide a clearer picture of the factors contributing to a crash. This may be particularly relevant to truck crashes, where the driver is often an employee, and the chain of responsibility laws mean there is the potential for serious consequences, not only for the driver, but for all those included in the responsible chain. The independence of the organisation conducting the no-blame investigations also assists the investigators to make judgements free from bias, conscious or unconscious, that may occur as a result of organisations having an interest in determining liability and / or taking criminal, regulatory, or administrative action.

Another defining characteristic of in-depth no-blame crash investigations is the involvement of a multi-disciplinary team. To obtain a multi-faceted understanding of the crash, investigators need expertise in the various disciplines related to road safety. Typically, the team may include experts in automotive or mechanical engineering, traffic or civil engineering, human factors or psychology, and medicine. The composition of this multi-disciplinary team aligns with the types of data typically collected, including data on the vehicle(s), road(s), road users involved and their behaviour, and injuries sustained in the crash. A multi-disciplinary team also enables the interpretation of the collected data from multiple perspectives, reducing the potential for discipline-specific biases.

1.4. Aim of the present study

There have been several crash investigation studies conducted over the years in Australia. No-blame investigations of crashes have been conducted by the Centre for Automotive Safety Research (CASR) and its predecessors in South Australia for many decades (McLean, 1973; McLean, 2005; Doecke, Thompson & Stokes, 2020), and a recent no-blame crash investigation study was conducted in Victoria by the Monash University Accident Research Centre and Transport Accident Commission (Fitzharris *et al.*, 2020). However, none of these in-depth no-blame crash investigation studies in Australia have focussed on truck crashes. While truck crashes will certainly be present in the samples of these studies, the absence of a specific focus on truck crashes means that the proportion of the crashes investigated will be small. For example, in CASR's current series of in-depth crash investigations, truck crashes make up fewer than 9% of all crashes.

There are crash investigations conducted in Australia that do focus on trucks but cannot be considered no-blame investigations. The National Transport Insurance's (NTI) National Truck Accident Research Centre (NTARC) produces an annual report based on NTI's investigations of incidents with a loss of $50,000 or more (Gibson, 2022). In 2021 there were just over 1000 incidents that involved NTI insured trucks that met this criterion. While these reports (and the investigations they are based on) are of value, they cannot be considered no-blame investigations as NTI has interest in determining liability and are therefore not independent. It is also unclear if these investigations use a multi-disciplinary approach.

The aim of the present study was to undertake a substantial sample (n=100) of in-depth no-blame crash investigations of crashes involving trucks to identify the factors that contribute to their occurrence, and the interventions that show the most potential to prevent or mitigate truck crashes.

The present report focuses on detailing the following:

- the methods used to investigate crashes involving trucks,
- the representativeness of the sample of crashes that were investigated,
- the proportion of cases for which the different types of investigation data were collected or produced, (e.g., proportion of drivers interviewed)
- the factors that were identified as contributing to the crashes, and
- the interventions that have the potential to prevent crashes involving trucks or mitigate resulting injuries.

2. Method

The 100 crashes involving trucks that were investigated for this report came from two distinct time periods, in which slightly different methods were used. CASR – which was formally known as the Road Accident Research Unit or RARU – has been conducting in-depth no-blame crash investigations in South Australia (SA) in various forms since the 1970s. CASR's most recent series of crash investigations began in October 2014 and has included crashes involving trucks, though they were not a specific focus. In July 2021, CASR received funding from the Office of Road Safety's Road Safety Innovation Fund to undertake additional no-blame crash investigations focussed on trucks and increase the total number of no-blame truck crash investigations to 100. These were conducted between July 2021 and February 2023. There were 32 pre-existing investigations of crashes involving trucks that were conducted between October 2014 and June 2021 as part of ongoing CASR in-depth activities. A further 68 crashes involving trucks were investigated between July 2021 and February 2023 to reach the target sample of 100 crashes. The following section will detail the methods used over both time periods.

Much of the data collection detailed in this section is enabled by pre-existing authorisations, approvals, memorandums of understanding, agreements, and relationships built up over the many decades that CASR has been conducting in-depth no-blame crash investigations, though some required modification for this study. The most important of these is that CASR's Road Trauma Analysis (of which this study is a part) is an authorised research activity under the South Australian *Health Care Act 2008*. Ethics approval was granted by the SA Department for Health and Wellbeing Human Research Ethics Committee (2021/HRE00231). Other SA agencies or bodies with which CASR has approvals, memorandums of understanding and agreements that enabled data collection for this study include the Police, the Ambulance Service, the Department for Infrastructure and Transport, the Coroner's Office, and several major hospitals. Furthermore, the relationships CASR has built with various towing companies and vehicle holding yards across SA over many years also greatly assisted the data collection process.

2.1. Area of investigations

For the on-going in-depth investigations conducted by CASR, a team of two investigators attend a metropolitan crash if it occurs in the city of Adelaide or the surrounding suburbs, within a 30 km radius of the CASR office located in the Adelaide CBD. They attend a rural crash if it occurs within a 100 km radius of the Adelaide CBD. These distance limitations were established to increase the chance that evidence at the crash scene remains intact when the investigation team arrives. The objective is to reach metropolitan crashes within 30 minutes and rural crashes within 1.5 hours. The shorter time limit for travel to metropolitan crashes compared to rural crashes was based on observations by investigators that evidence at the scene of metropolitan crashes is typically cleared more rapidly. Factors such as shorter distances for tow trucks to travel and traffic flow restoration being considered more urgent likely contribute to this. Rural crashes occurring within a rural township are not attended by CASR investigators as the road conditions and speed limits in townships are similar to city and suburban areas, which are already covered by the investigations of metropolitan crashes. Additionally, crashes in rural townships have been found to be cleared in a similar timeframe to metropolitan crashes, which often limits the opportunity for CASR investigators to reach the scene in a timely manner.

For the truck specific investigations, the range was extended to a maximum of 200 km. However, the decision to proceed with an investigation was contingent upon the likelihood of crash investigators being able to reach the scene before evidence was removed. This determination was primarily based on whether the truck involved in the crash was rendered incapacitated. Trucks that were still driveable typically remained at the crash scene until the completion of any formal obligations, after which they would leave the scene with the permission of attending police. This process generally required less than an hour to complete. In contrast, trucks requiring towing remained at the crash scene for an extended period, often several hours. This is partially due to long travel times for heavy tow trucks. Additionally, the process of towing a crashed truck can require considerably more planning, preparation and logistics compared to towing a light vehicle, especially if the truck is loaded and/or it is in a difficult position for recovery (e.g., rolled on its side, travelled off-road or down an embankment, etc.). Some attempts were made to ascertain if a truck was going to require a heavy tow truck through the police or heavy tow truck companies, but these had only very limited success. In general, investigators made a judgement based on the initial information they had about the crash through the pager messages sent to the fire services, and information discussed over ambulance radio systems (see Sections 2.3 and 2.4).

2.2. Time of day and day of week of investigations

At-scene investigations

During the initial period of the on-going CASR in-depth crash investigations commencing in 2014, the investigative team was on-call from the CASR office in the Adelaide CBD to promptly respond to crashes during two shifts: 9am to 2pm and 2pm to 9pm, from Monday to Friday. In October 2019, the earlier shift was adjusted to 7am to 2pm to capture the morning peak-hour and enhance the representativeness of the crash sample. Additionally, on weekends, shifts covering the same hours on Saturdays, and 9am to 9pm on Sundays (over two shifts) were introduced. These weekend shifts were not conducted with the same frequency as the weekday shifts.

In July 2020, specific on-call shifts for truck crashes were implemented. These shifts took place from Monday to Friday, either from 7am to 5pm or 9am to 5pm. For shifts commencing at 7am, staff members were not required to be present at the CASR office until 9am. However, if a truck crash occurred before 9am, they were instructed to rendezvous with the other investigator, and proceed directly to the crash scene. Approximately two-thirds of the truck-specific shifts commenced at 7am.

Regular shifts for ongoing CASR in-depth activities, covering crashes involving all motor vehicles, continued during this period. Typically, regular shifts and truck-specific shifts followed an alternating-day pattern, though there were some weeks where only truck-specific shifts were scheduled. A modification was made to the regular on-call shifts, whereby investigators monitored the notification system while investigating at the scene of a crash, and if a truck crash occurred after completing the initial time-critical at-scene tasks (e.g., marking evidence, speaking to police and witnesses), investigators left to attend the truck crash, and subsequently returned later to the original crash scene to complete the non-time-critical tasks.

Follow-up investigations

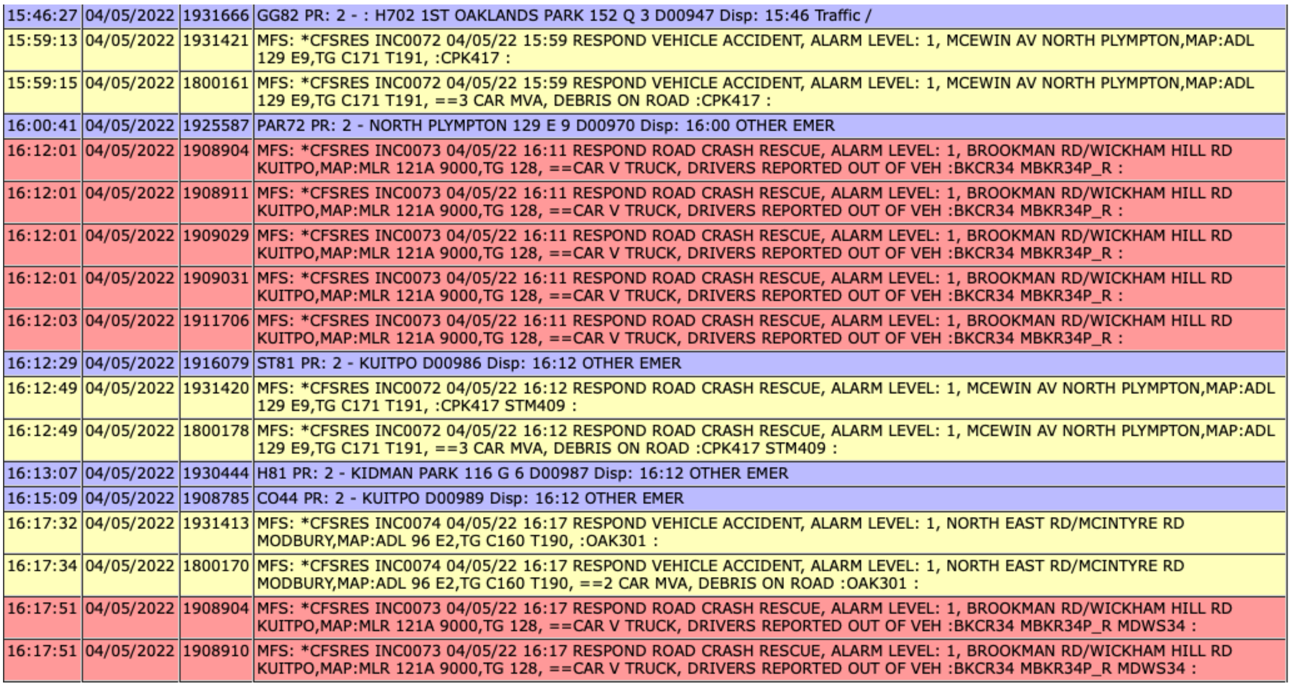
In addition to the standard on-call hours detailed above, CASR also carries out follow-up crash investigations for crashes that occur outside these hours that are investigated by SA Police’s Major Crash Investigation Section (MCIS). This is enabled by MCIS’s investigation techniques which involve the crash scene evidence being marked, and the vehicles often being seized as evidence.

MCIS investigates crashes in which a fatality has occurred, or when it is deemed that a crash participant may die as a result of the crash. MCIS may also be called on to investigate high-profile crashes. CASR's follow-up investigations typically begin the next weekday after the crash occurs.

2.3. Crash notification

CASR receives notifications of crashes through the SA Government Radio Network (GRN) paging system. Originally, CASR was equipped with a pager provided by the SA Ambulance Service (SAAS). Whenever an ambulance was paged about a vehicle crash, CASR would also be paged. Recently, CASR developed its own notification system, with guidance from SAAS, utilising a radio scanner and computer system that logged GRN paging messages. The system automatically generates emails to a dedicated phone whenever a GRN message meets specific criteria, thereby alerting the crash investigators about the occurrence of a crash.

The GRN paging system encompasses communications directed to the ambulance service, the fire services (metropolitan and country) and the state emergency service. Messages to the fire services pertaining to a vehicle crash contain the most detailed information regarding the types of vehicles involved. These messages typically include specific text such as "CAR VS TRUCK". The pager messages for the pre-existing 32 crashes involving a truck that CASR had investigated were reviewed to identify keywords to flag when a pager message refers to a truck crash. All but one of the pre-existing truck crashes that had been investigated would have been identified using the chosen keywords, with the exception being due to the truck's involvement being limited to a secondary minor impact, rather than the primary impact. Figure 2.1 illustrates an example of pager messages, with truck-specific messages highlighted in red.



15:46:27	04/05/2022	1931666	GG82 PR: 2 - : H702 1ST OAKLANDS PARK 152 Q 3 D00947 Disp: 15:46 Traffic /
15:59:13	04/05/2022	1931421	MFS: *CFSRES INC0072 04/05/22 15:59 RESPOND VEHICLE ACCIDENT, ALARM LEVEL: 1, MCEWIN AV NORTH PLYMPTON,MAP:ADL 129 E9,TG C171 T191, :CPK417 :
15:59:15	04/05/2022	1800161	MFS: *CFSRES INC0072 04/05/22 15:59 RESPOND VEHICLE ACCIDENT, ALARM LEVEL: 1, MCEWIN AV NORTH PLYMPTON,MAP:ADL 129 E9,TG C171 T191, ==3 CAR MVA, DEBRIS ON ROAD :CPK417 :
16:00:41	04/05/2022	1925587	PAR72 PR: 2 - NORTH PLYMPTON 129 E 9 D00970 Disp: 16:00 OTHER EMER
16:12:01	04/05/2022	1908904	MFS: *CFSRES INC0073 04/05/22 16:11 RESPOND ROAD CRASH RESCUE, ALARM LEVEL: 1, BROOKMAN RD/WICKHAM HILL RD KUITPO,MAP:MLR 121A 9000,TG 128, ==CAR V TRUCK, DRIVERS REPORTED OUT OF VEH :BKCR34 MBKR34P_R :
16:12:01	04/05/2022	1908911	MFS: *CFSRES INC0073 04/05/22 16:11 RESPOND ROAD CRASH RESCUE, ALARM LEVEL: 1, BROOKMAN RD/WICKHAM HILL RD KUITPO,MAP:MLR 121A 9000,TG 128, ==CAR V TRUCK, DRIVERS REPORTED OUT OF VEH :BKCR34 MBKR34P_R :
16:12:01	04/05/2022	1909029	MFS: *CFSRES INC0073 04/05/22 16:11 RESPOND ROAD CRASH RESCUE, ALARM LEVEL: 1, BROOKMAN RD/WICKHAM HILL RD KUITPO,MAP:MLR 121A 9000,TG 128, ==CAR V TRUCK, DRIVERS REPORTED OUT OF VEH :BKCR34 MBKR34P_R :
16:12:01	04/05/2022	1909031	MFS: *CFSRES INC0073 04/05/22 16:11 RESPOND ROAD CRASH RESCUE, ALARM LEVEL: 1, BROOKMAN RD/WICKHAM HILL RD KUITPO,MAP:MLR 121A 9000,TG 128, ==CAR V TRUCK, DRIVERS REPORTED OUT OF VEH :BKCR34 MBKR34P_R :
16:12:03	04/05/2022	1911706	MFS: *CFSRES INC0073 04/05/22 16:11 RESPOND ROAD CRASH RESCUE, ALARM LEVEL: 1, BROOKMAN RD/WICKHAM HILL RD KUITPO,MAP:MLR 121A 9000,TG 128, ==CAR V TRUCK, DRIVERS REPORTED OUT OF VEH :BKCR34 MBKR34P_R :
16:12:29	04/05/2022	1916079	ST81 PR: 2 - KUITPO D00986 Disp: 16:12 OTHER EMER
16:12:49	04/05/2022	1931420	MFS: *CFSRES INC0072 04/05/22 16:12 RESPOND ROAD CRASH RESCUE, ALARM LEVEL: 1, MCEWIN AV NORTH PLYMPTON,MAP:ADL 129 E9,TG C171 T191, :CPK417 STM409 :
16:12:49	04/05/2022	1800178	MFS: *CFSRES INC0072 04/05/22 16:12 RESPOND ROAD CRASH RESCUE, ALARM LEVEL: 1, MCEWIN AV NORTH PLYMPTON,MAP:ADL 129 E9,TG C171 T191, ==3 CAR MVA, DEBRIS ON ROAD :CPK417 STM409 :
16:13:07	04/05/2022	1930444	H81 PR: 2 - KIDMAN PARK 116 G 6 D00987 Disp: 16:12 OTHER EMER
16:15:09	04/05/2022	1908785	CO44 PR: 2 - KUITPO D00989 Disp: 16:12 OTHER EMER
16:17:32	04/05/2022	1931413	MFS: *CFSRES INC0074 04/05/22 16:17 RESPOND VEHICLE ACCIDENT, ALARM LEVEL: 1, NORTH EAST RD/MCINTYRE RD MODBURY,MAP:ADL 96 E2,TG C160 T190, :OAK301 :
16:17:34	04/05/2022	1800170	MFS: *CFSRES INC0074 04/05/22 16:17 RESPOND VEHICLE ACCIDENT, ALARM LEVEL: 1, NORTH EAST RD/MCINTYRE RD MODBURY,MAP:ADL 96 E2,TG C160 T190, ==2 CAR MVA, DEBRIS ON ROAD :OAK301 :
16:17:51	04/05/2022	1908904	MFS: *CFSRES INC0073 04/05/22 16:17 RESPOND ROAD CRASH RESCUE, ALARM LEVEL: 1, BROOKMAN RD/WICKHAM HILL RD KUITPO,MAP:MLR 121A 9000,TG 128, ==CAR V TRUCK, DRIVERS REPORTED OUT OF VEH :BKCR34 MBKR34P_R MDWS34 :
16:17:51	04/05/2022	1908910	MFS: *CFSRES INC0073 04/05/22 16:17 RESPOND ROAD CRASH RESCUE, ALARM LEVEL: 1, BROOKMAN RD/WICKHAM HILL RD KUITPO,MAP:MLR 121A 9000,TG 128, ==CAR V TRUCK, DRIVERS REPORTED OUT OF VEH :BKCR34 MBKR34P_R MDWS34 :

Figure 2.1
Example of messages from GRN pager system (red relates to truck-specific crashes)

2.4. Severity criterion

CASR's on-going crash investigations have a severity criterion of ambulance transport. That is, one crash participant must be transported by ambulance to a hospital or similar medical facility for a crash to be investigated. The decision to transport a patient to hospital or not is communicated over the SAAS radio system. CASR has been provided with a SAAS radio, which allows crash investigators to discontinue their response if it becomes known that the severity criterion will not be met while the investigators are en route to the crash scene.

Some modifications were made to the severity criterion for the truck-specific investigations. Truck rollovers and crashes involving trucks on high-speed roads (speed limits of 100 and 110 km/h) were included in the truck-specific sample, even if no crash participants required hospital transport. The rationale behind this adjustment was the hypothesis that these types of crashes inherently carried a higher probability of injury and therefore warranted inclusion in the investigation sample, regardless of the actual outcome.

2.5. At-scene data collection

At-scene data collection for the in-depth no-blame crash investigations (both ongoing and truck specific) comprises various components, which are described in detail in this section. Due to the dynamic nature of crash scenes, the specific order in which data are collected vary on a case-by-case basis. For example, participants and witnesses who possess valuable information about the crash often leave the scene quickly, while in other crashes it is the vehicles that are relocated or removed first. This can change the priorities of investigation. Investigators rely on their experience to prioritise the collection of evidence, considering the unique circumstances of each case.

It should be noted that CASR's investigators did not possess direct authority over crash scenes and are not empowered to issue instructions to individuals present at the scene. However, over the years of conducting at-scene crash investigations, CASR has established a positive working relationship with the emergency services who hold authority over crash scenes. Additionally, CASR fostered connections with other entities involved in the process, such as towing companies and their associated crash repairers. These longstanding relationships prove invaluable in assisting CASR's at-scene data collection efforts.

2.5.1. Marking the evidence left on the road and roadside.

A vehicle crash typically leaves behind various types of evidence on the road and its surroundings. These include tyre marks, scrapes, scuffs, gouges, vehicle fluids, human biological matter, and even dirt dislodged from the vehicle as a result of the crash. CASR crash investigators use brightly coloured paint to highlight any road and roadside evidence, ensuring its visibility in photographs and to the device used to digitally measure the crash scene and record the evidence (see Section 2.5.7 for description of this device).

Tyre marks observed at the scene provide valuable insights into braking, sliding, and uneven loads on specific wheels, which are often indicative of conditions preceding a truck rollover. Examples of commonly encountered truck tyre marks at crash scenes are shown in Figure 2.2. The image on the left shows tyre marks from braking, and the image to the right shows tyre marks that preceded a rollover.

Figure 2.2
Examples of truck tyre marks from braking (left) and preceding a rollover (right)

Scrapes, scuffs, and gouges on the road surface near the point of impact can indicate contact between vehicle components and the road as a result of collision forces. Additionally, scrapes and gouges are commonly observed when a vehicle rolls over, showing where various parts of the vehicle structure made contact with the ground. In cases involving collisions with pedestrians, scuff marks starting from the point of impact might be left by the shoes of the pedestrian. Scuff marks on the road can also be caused by the clothing of pedestrians, cyclists, or motorcyclists when they come into contact with the road surface. Figure 2.3 provides an example of scrape and gouge marks left by a vehicle close to the point of impact. These occurred due to the collision forces causing parts of the vehicle to come into contact with the road.

Figure 2.3
Example of scrape marks on a road close to the point of impact from collision forces causing parts of the vehicle to come into contact with the road

Fluid marks on the road or roadside can be evidence of fluid leakage from a vehicle's systems when they are ruptured during a crash. In the case of light vehicles, frontal impacts often result in fluid spills from the radiator, associated hoses, or pipes. Fluid leaks from radiator damage in frontal impacts are less common in trucks, particularly larger trucks. For larger trucks, fluid leaks are more likely to occur in impacts involving side-mounted fuel tanks. Fluid marks are typically observed in the vicinity of the impact point, with a trail of fluid indicating the vehicle's path from the initial impact position to its final resting position. An example of a fluid mark is shown in Figure 2.4.

Figure 2.4
Example of fluid marks on a road left by a vehicle involved in a crash

Marks from human biological matter typically occur in crashes between trucks and vulnerable road users, although they are possible in all crashes. These marks often consist of blood, which can be observed on the road surface, often serving as an indication of the road surface contact points of a person involved in the crash. A large amount of blood at a specific location often indicates the final resting position of an individual. Figure 2.5 provides an example of blood on a road surface, representing the first road surface contact point of a vulnerable road user in a crash involving a truck.

Figure 2.5
Example of blood on the road from a vulnerable road user struck by a truck

Dirt patches at a crash scene often serve as additional evidence to determine the location of the point of impact. The impact forces of certain crashes cause dirt to be dislodged from the undercarriage of vehicles, leaving traces on the road surface. Figure 2.6 presents an example of dirt on the road resulting from a vehicle involved in a crash.

Figure 2.6
Example of dirt on the road dislodged from a crash-involved vehicle, indicating the point of impact

2.5.2. Vehicle final rest positions

Establishing the final rest positions of vehicles is of great importance to performing an accurate crash reconstruction. As vehicles are often moved soon after a crash, marking the final positions is often one of the first tasks the crash investigators complete. If the vehicles have been moved to clear the road or driven away from the crash scene before CASR investigators arrive, other types of evidence, such as fluid marks or tyre marks are relied upon to establish the final rest positions. In certain cases, photographs taken by emergency services or camera footage are relied upon in this determination. Figure 2.7 demonstrates the final position markings of a truck involved in a crash.

[redacted]
[redacted]
[redacted]

Figure 2.7
Final position markings for a truck involved in a crash

2.5.3. At-scene discussions

Engaging in discussions with individuals present at the crash scene is valuable for obtaining initial information about the crash. CASR investigators adhere to a protocol by which they are required to approach the person in charge of the crash scene, typically a police officer or a representative from the fire service, to inform them of their attendance. This ensures that CASR's investigation activities, such as marking the evidence, do not interfere with the important work being carried out by the emergency services. The person in charge provides CASR's investigators with an initial understanding of the crash, while additional discussions are also conducted with the fire services if necessary. Conversations with the ambulance officers are infrequent and only pursued if it is not a distraction from their duties, and if it can add an important piece of information to the investigation.

CASR investigators also have brief discussions with uninjured crash participants and witnesses who are still present at the scene upon their arrival. Detailed discussions with crash participants are specifically avoided at the crash scene, due to ethical considerations regarding the principles of informed consent. However, CASR investigators have found that the initial establishment of rapport benefits the later contact with individuals and the request for them to participate in detailed interviews, in particular through introducing themselves to crash participants, explaining their reason for attending the crash scene, explaining the independent and confidential nature of CASR investigations, and providing them with a participant information sheet.

2.5.4. Vehicle examination

Vehicle examinations are typically conducted at the crash scene. These examinations include photography, measurement, and the recording of information (Figure 2.8). Photography is focused on capturing evidence of exterior deformation, interior intrusion, points of contact between the occupant and the vehicle's interior, the functioning of vehicle safety systems, the driver's point of view (including any blind spots), and potential vehicle defects.

The following measurements are taken:

- Extent of deformation to the vehicle (e.g., depth and length of damage/intrusion).
- Tyre tread depth.
- Tyre pressures (light vehicles only).
- Total length of vehicle.
- Total width of vehicle.
- Front overhang (distance between front of vehicle and front axle).
- Wheelbase (Distance between front and rear axles of vehicle).
- Rear overhang (distance between rear of vehicle and rear axle).

In addition to the measurements, the following information is recorded:

- Evidence of seatbelt wearing (e.g., seatbelt scuffing).
- Whether airbags were deployed or not.
- Tyre specifications (e.g., brand, type, and size).
- Vehicle make, model, and build date.
- Vehicle Identification Number (VIN).

- Transmission type (e.g., automatic or manual).
- Registration number.
- Vehicle colour.
- Presence of bulbar and construction material.
- Impact location(s).
- Presence of vehicle safety technologies (e.g., ESC).

Certain information specific to heavy vehicles is also recorded, including:

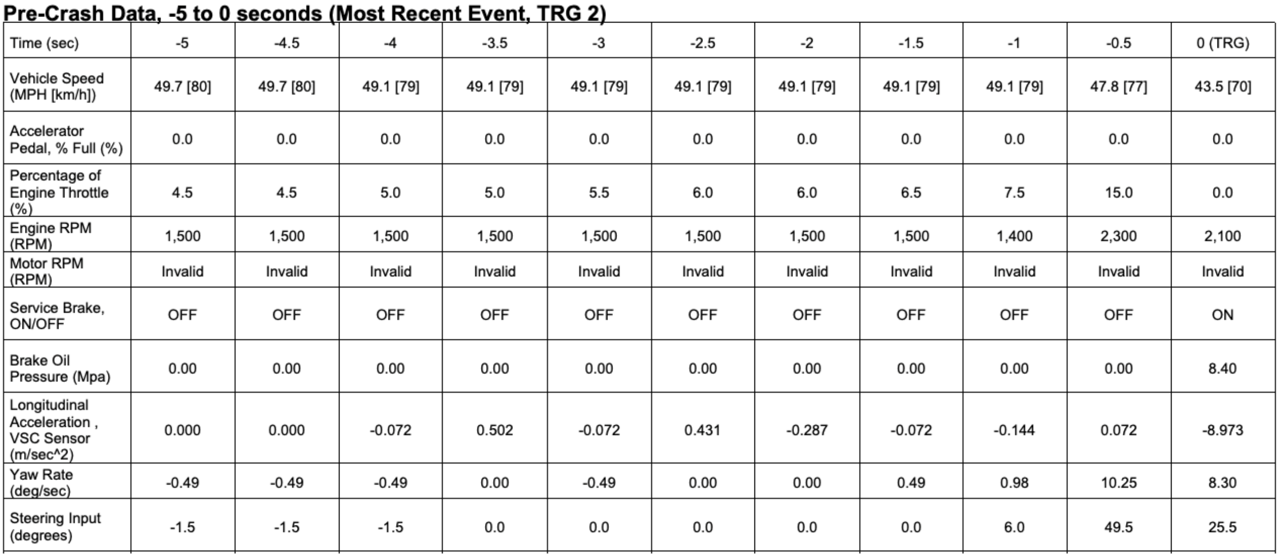
- Gross Vehicle Mass (GVM), Gross Combination Mass (GCM), and Aggregated Trailer Mass (ATM) of heavy vehicles.
- Specific type of braking system.
- General standard or appearance of maintenance (e.g., poor, good).
- Nature of load (e.g., hay, concrete).
- Brake pressure.
- Wheel nut alignment (if specific alignment indicators were used).

Figure 2.8
A CASR investigator in the process of examining a truck

Full mechanical inspections of vehicles are not conducted by CASR investigators. During the initial stages of the investigations focusing on trucks, informal instruction on heavy vehicle brake inspection was provided by SA Police Major Crash Investigation Unit mechanics. This instruction covered the assessment of brake pads to ensure adequate contact when applied, and the measurement of the pushrod stroke angle for airbrake systems. However, applying these techniques consistently in the field proved challenging for a variety of reasons, including time constraints and safety concerns regarding an investigator being underneath a truck that was not disabled.

EDR data

The CASR vehicle examination process also includes the retrieval of information from the Event Data Recorder (EDR) of light vehicles, whenever it is accessible. EDRs are designed to detect crashes and record up to five seconds of data leading up to the crash event. The data provided by EDRs include important information such as travel speed, impact speed, restraint use, brake/accelerator pedal position, crash impact severity (delta-*v*), deployment of safety features such as airbags, and steering wheel angle. Only EDRs compatible with the Bosch Crash Data Retrieval tool are currently downloaded during CASR investigations. This tool supports data retrieval from various vehicle models, including most Toyotas built after 2003, many Holdens built after 2007, most Subarus built after 2013, some Mitsubishis built after 2011, and Jeeps built after 2006. An example of the pre-crash data provided by an EDR is shown in Figure 2.9, demonstrating the timesteps of data recorded before the crash.



Pre-Crash Data, -5 to 0 seconds (Most Recent Event, TRG 2)

Time (sec)	-5	-4.5	-4	-3.5	-3	-2.5	-2	-1.5	-1	-0.5	0 (TRG)
Vehicle Speed (MPH [km/h])	49.7 [80]	49.7 [80]	49.1 [79]	49.1 [79]	49.1 [79]	49.1 [79]	49.1 [79]	49.1 [79]	49.1 [79]	47.8 [77]	43.5 [70]
Accelerator Pedal, % Full (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Percentage of Engine Throttle (%)	4.5	4.5	5.0	5.0	5.5	6.0	6.0	6.5	7.5	15.0	0.0
Engine RPM (RPM)	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,400	2,300	2,100
Motor RPM (RPM)	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Service Brake, ON/OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON
Brake Oil Pressure (Mpa)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.40
Longitudinal Acceleration , VSC Sensor (m/sec^2)	0.000	0.000	-0.072	0.502	-0.072	0.431	-0.287	-0.072	-0.144	0.072	-8.973
Yaw Rate (deg/sec)	-0.49	-0.49	-0.49	0.00	-0.49	0.00	0.00	0.49	0.98	10.25	8.30
Steering Input (degrees)	-1.5	-1.5	-1.5	0.0	0.0	0.0	0.0	0.0	6.0	49.5	25.5

Figure 2.9
Example of EDR data from a light vehicle

Trucks do not record crash-specific information in the same manner as light vehicles. However, truck Engine Control Units (ECUs) do capture certain data under specific conditions, which may include crash scenarios. Although the possibility of acquiring equipment to download information from truck ECUs was considered, it was ultimately not pursued due to the cost being considerable. Additionally, the value of the information obtained from a truck ECU in the context of a truck crash was unclear, and it was uncertain if truck drivers and companies would grant CASR investigators permission to connect electronic devices to their trucks for the retrieval of stored data.

2.5.5. Private camera footage

Private camera footage relating to a crash has become increasingly common and can provide a wealth of information for a crash investigation. Dashcams are the most common form of private camera footage that captures a crash but private surveillance cameras attached to a business or residence also capture crashes, or vehicle movements and actions prior to a crash.

Dashcams on trucks typically consist of a forward-facing camera but some also include a camera facing the driver. Some cameras have overlays displaying information such as the time and date, vehicle speed, GPS coordinates and accelerometer measurements. Figures 2.10 and 2.11 illustrate examples of the field of view captured by dashcams and the information contained in an overlay. The displayed vehicle speed on dashcam footage is typically based on GPS-position data, providing a reliable indication of travel speed prior to a crash. However, it may not accurately represent the impact speed in cases in which significant pre-impact braking occurs, due to slow refresh rates. CASR found truck drivers and companies were generally cooperative when approached to provide copies of their dashcam footage for the purpose of a no-blame investigation.

Figure 2.10
Example of dashcam footage from a truck involved in a crash with an overlay showing speed (date redacted)

Figure 2.11
Example of a dashcam view from a truck involved in a crash without an overlay showing speed (date redacted)

2.5.6. Road and environment examination

The road and roadside environment are systematically examined for factors that may have contributed to the crash. A sequence of photographs is taken from the approach directions of each vehicle, to the point of impact, and along their post-impact travel path to their final resting positions. Particular attention is paid to the presence of any road defects, sight lines on the approach to intersections, delineation, and signage. The length of the photographed approach varies, typically spanning 50 to 150 metres, depending on the road environment.

In addition to photographs, drive-through videos are recorded using CASR's crash investigation vehicle. These videos provide a dynamic perspective of the approach, with the camera facing forward and, in the case of intersection-related crashes, to the sides. The length of the drive-through videos varies based on the road environment, generally covering a range of 500 metres to two kilometres. While photographs offer a specific angle of the road and environment, drive-through videos provide an understanding of the driver's perspective, including the rate at which information was presented to the driver, and the timing between various driving-related tasks. Static videos are occasionally recorded to observe the behaviour of other drivers using the same road segment, or to capture dynamic elements of the road environment, such as the sequencing of traffic signals. Figure 2.12 provides an example of a photograph showing the view to the right on the approach to an intersection controlled by a give-way sign. The presence of a large sign can obscure the view of vehicles if the driver fails to stop at the intersection and instead looks to the right while still in motion. Figure 2.13 shows a section of road where the edge of the bitumen has broken away, with uneven remedial patching lower than the main road surface.


[redacted]

Figure 2.12
Example of a site photograph illustrating a visual obstruction (sign content redacted)

Figure 2.13
Example of a site photograph where the road edge has uneven remedial patching

2.5.7. Site measurement

The crash site is digitally mapped using advanced surveying equipment shortly after the occurrence of the crash. The purpose of site measurement is to capture detailed information about the road features, roadside elements, and the specific crash scene evidence marked by the investigators using paint (see Sections 2.5.1 and 2.5.2). Prior to 2018, the digital site mapping process involved surveying using a Leica total station, shown in Figure 2.14. Individual points were recorded, with each point classified according to its type. In 2018, the total station method was replaced by a more advanced 3D scanner, specifically the Faro Focus S70, as depicted in Figure 2.15. The 3D scanner is positioned at various locations around the crash scene to perform multiple scans. Each scan takes between 90 seconds and 10 minutes to complete, depending on desired resolution quality and the need to capture colour (required for evidence marked with paint). The scanner has a reliable scanning radius of approximately 20 to 30 metres and collects between 43 million and 175 million points per scan. The use of the 3D Scanner was aimed at improving efficiency at the crash scene, reducing the time spent by crash investigators near traffic and improving the quality and quantity of site data collected. The collected scans are processed by aligning and joining them in a process called registration, to create a point cloud, which is then exported to a line drawing program. In this program, lines are superimposed over the 3D point cloud, resulting in a configuration ready for the creation of a site diagram (see Section 2.6.4).

Figure 2.14
Total station surveying equipment in-use at a crash scene

Figure 2.15
3D scanning equipment in-use at a crash scene

2.6. Further data collection, processing, and analysis

The data collection process extends beyond the initial scene investigation to data collection, processing, and analysis undertaken after the CASR investigators return from the crash scene. Post-crash data collection involves multiple sources of data, including police reports, detailed injury data, vehicle specification data (e.g., safety equipment), and interviews conducted with both the roads users involved and any witnesses of the crash. Additionally, crash histories of specific road locations, and the crash and traffic offence history of drivers and riders are examined. In cases involving fatalities, the Coroner’s file is obtained to provide further insights into the crash. Footage from traffic cameras operated by the Department for Infrastructure and Transport’s Traffic Management Centre is also collected if available at the crash location. The processing of the crash scene measurement into a site diagram and a crash reconstruction are also important steps in the investigation procedure.

2.6.1. Police reports

The police reports contain several important pieces of information that assist in the investigations. They provide details about the road users (drivers, riders, and pedestrians) involved in the crash and any injured vehicle passengers; results from alcohol and drug tests; and a brief narrative of the crash.

Basic information about the drivers, riders, pedestrians, and any injured passengers includes their name, address (can include multiple addresses), date of birth, gender, seat position, licence number, licence jurisdiction (e.g., SA), licence class (e.g., car, motorcycle, etc.), and licence status (e.g., full, expired, learner, etc.). In addition to providing demographic and licensing data, this information is used to contact individuals involved in the crash to request an interview. It is also used to match the police-reported data with hospital records related to the crash, as well as crash and traffic offence records.

Police reports include basic injury details, providing information about the severity of injuries based on the level of medical treatment required. The severity categories typically include doctor (GP) treatment, treatment at the hospital, admission to the hospital, or a fatality. The nature of the injury is also documented, although these details are primarily based on the initial assessment conducted by ambulance paramedics at the scene and may not necessarily align with the diagnosis made at the hospital. Nevertheless, these initial injury details provide a preliminary indication of the level of injury sustained. Furthermore, the police reports also specify the hospital attended by the individuals, which helps facilitate the collection of more detailed injury information.

The police reports serve as the primary source of drug and alcohol test results. If the driver or rider does not go to a hospital, these fields are based on the roadside test conducted by the police officer, as well as any subsequent tests administered. For cases in which the driver or rider is transported to a hospital, the test results are obtained from blood tests conducted at the hospital. The alcohol test results provide the concentration level, while drug tests results do not specify an exact level. This poses challenges in determining the extent to which the drug may have impaired the driver or rider, as drug presence can be detected in an individual for an extended period of time beyond initial use. The drugs tested for are cannabis (referred to as THC in police reports, derived from its principal psychoactive constituent, delta-9-tetrahydrocannabinol), methamphetamine (referred to as METH in police reports, colloquially known as ‘speed’ or ‘ice’) and MDMA (Methylenedioxymethamphetamine, colloquially known as ‘ecstasy’).

Police reports include a narrative of the crash. These appear to be based on the driver’s statements as to what happened, witnesses’ statements, and the officer’s judgement of what occurred. While not necessarily objective, these can provide useful insight into what is thought to have occurred, though they vary greatly in the level of detail recorded.

A section of the police report allows the recording of “contributing circumstances” attributed to an involved individual. This section provides details regarding the intended action, errors and contributing factors associated with the driver’s involvement in the crash. The selection of errors is typically not informative beyond indicating who the police deem to be at fault. While multiple contributing factors can be selected, often only one is chosen. Additionally, an “Other” field allows the police to include any relevant notes they deem necessary for the contributing circumstances, although it is not commonly utilised. When utilised, it can provide some helpful additional insights.

2.6.2. Interviews

Interviews are undertaken with the participants (i.e., drivers, pedestrians, riders) and/or witnesses of the crash not less than five weeks after the crash. The purpose of each interview is to obtain the participants' recollection of the crash, their demographic and other background information, and information relating to the crash involved vehicle. This self-report information is important for supplementing data collected at the scene of the crash to build a comprehensive understanding of the crash dynamics, including the specific circumstances that led up to the crash.

Upon their arrival, and where appropriate, CASR crash investigators approach participants, family members and witnesses remaining at the scene to briefly introduce themselves and to provide them with a participant information sheet. In circumstances where investigators are unable to communicate with participants at the scene, an introductory letter and participant information sheet are posted to their home address. The information sheet introduces the research study and informs them of its purpose, what an interview involves, and that participation is voluntary and confidential. Potential interview participants are advised that a CASR researcher will contact them by telephone to enquire if they would like to be involved. A different approach is taken to interview recruitment when a crash has resulted in a fatality. These potential interview participants are not approached at the scene, but rather are sent a letter, consent form and participant information sheet introducing the study. The letter expresses an understanding of the sensitive and traumatic nature of the crash together with a reply-paid self-addressed envelope inviting them to return this to CASR should they like to be involved in the follow-up interview. In the event that they do not return the consent form, no further follow-up is undertaken. In cases in which the fatally injured person was known to the participant who was also involved in, or witnessed the crash (i.e., a family member or friend) no follow-up letter is posted to them out of respect for their privacy throughout that extremely traumatic time. At the time of telephone contact, if the participant agrees to an interview, a mutually suitable time is arranged. Interviews were traditionally a mix of telephone interviews and in-person interviews (e.g., at a public place, the CASR office, or a participant's home), with the participant encouraged to choose the option they preferred. However, since the COVID-19 pandemic at the start of 2020, the majority of participants have opted to undertake the interview over the telephone.

Interviews generally take around 30 to 40 minutes but the duration is flexible and participants are encouraged to share as little or as much as desired. Participants are reminded that they are not obliged to answer any questions they prefer not to, and are free to withdraw from the interview at any time with no negative consequences. Interview questions are designed to collect data in the following broad areas of enquiry:

- Demographic and personal information of participant (e.g., date of birth, country of birth, highest level of education, usual occupation).
- Driving history (e.g., age when first licensed, how they learned to drive, previous crash and traffic offence history).
- Details of vehicle involved in crash (e.g., make and model, vehicle ownership, how many years they owned the vehicle, frequency driving that vehicle, known defects).
- Substance use and medications – typical and specific use on the day of crash (e.g., alcohol and recreational drug use, prescription and non-prescription medications, and caffeine and nicotine use).

- General medical and mental health (e.g., diagnosed medical conditions, or undiagnosed medical complaints [such as aches and pains, physical limitations]; mental health functioning/diagnoses).
- Crash details (e.g., lighting/weather/road conditions).
- Trip details (e.g., origin of trip, intended destination, familiarity with location).
- Road user risk factors (e.g., emotional state, sleep patterns generally and hours of sleep the night before crash, perceived fatigue level at the time of crash).
- Crash narrative (e.g., description of what happened, causes of the crash, travelling speed, attempts at crash avoidance such as braking and steering input).
- Injuries (e.g., details of injuries sustained, length of hospitalisation, impact on physical and mental health including limitations and long-term disabilities).
- Other people in vehicle (e.g., position in vehicle, belt use, injuries).

For the investigations specifically focussed on truck crashes, some additional questions were added after consultation with industry experts. These questions relate to:

- Maintenance of truck (by individual drivers and company).
- Company safety culture.
- Time pressure/financial consequences of running late.
- Proportion of rural and metro driving for work, also distance travelled on work shifts.
- Fatigue management practices (by individual driver and company).
- Specifics of any braking systems used during crash avoidance.

2.6.3. Detailed injury data collection

Detailed injury data are collected from five of the six major metropolitan hospitals in Adelaide: the Royal Adelaide Hospital, Flinders Medical Centre, the Queen Elizabeth Hospital, the Lyell McEwen Hospital, and Modbury Hospital. While CASR has ethics approval to collect data from the Women's and Children's Hospital and has received site specific approval in the past, collecting data from this hospital has proved challenging and was not pursued for the current study. Additionally, data collection from the Lyell McEwen Hospital and Modbury Hospital was paused in 2020, and all hospital data collection was paused in 2023 due to administrative issues. CASR's authorisation under Section 64 of the *Health Care Act 2008* enables the collection of patient injury information related to road trauma analysis hospital data without the need for patient consent. This authorisation enables the acquisition of detailed injury data for crash participants attending the aforementioned hospitals. Injury information cannot be obtained if the crash participant is treated at rural hospitals or clinics, minor metropolitan hospitals, the Women's and Children's Hospital, private hospitals, or general practice (GP) clinics. Crash participants with serious injuries are generally transported to major metropolitan hospitals, even if the crash occurred in a rural area. As a result, the inability to collect injury information primarily relates to crash participants with minor to moderate injuries, or children. In cases in which crash participants died at the scene, injury information is collected from Coroner's files. However, there is a significant time gap between a fatal crash occurring and the availability of Coroner's file for data collection by CASR, and not all Coroner's files were available within the timeframe of this study.

The collected injury data includes notes on the injuries sustained by crash participants from the ambulance service and hospital. The time of medical arrival and duration of hospitalisation are also recorded. While scans and radiology may be reviewed, copies of these are not collected as part of the data. All documented injuries are coded using the Abbreviated Injury Scale (AIS), which is an ordinal scale ranging from 1 to 6. AIS categorises injuries based on threat to life, mortality risk, and other factors, such as temporary and permanent disablement (Association for the Advancement of Automotive Medicine, 2018). The maximum AIS, referred to as MAIS, and the Injury Severity Score (ISS), are calculated for each injured person (using AIS) to give an overall measure of injury severity.

Minor injuries, such as contusions and abrasions, that are self-reported during an interview or observed at the crash scene are also coded using AIS, regardless of whether the person sought medical treatment at a hospital or had their hospital notes recorded. This ensures that even minor injuries can be included in the injury coding process.

2.6.4. Site diagram

The digital mapping of the crash scene using the total station or 3D scanner is used to create a site diagram. The purpose of the site diagram is to visually depict the sequence of events during the crash in a scaled format, including the initial positions and trajectories of the vehicles, impact positions, and final resting positions. The site diagram also incorporates the road layout, road features, and relevant crash scene evidence, such as tyre marks, scrape marks and fluid patches. Although it is presented as a 2D top-down view, the digital file retains the 3D information, allowing for measurements of 3D elements of the road or roadside. The site diagram is also used in the crash reconstruction process as it provides a scaled representation of key evidence such as tyre marks, impact positions, and final vehicle positions. An example of a site diagram is shown in Figure 2.16.

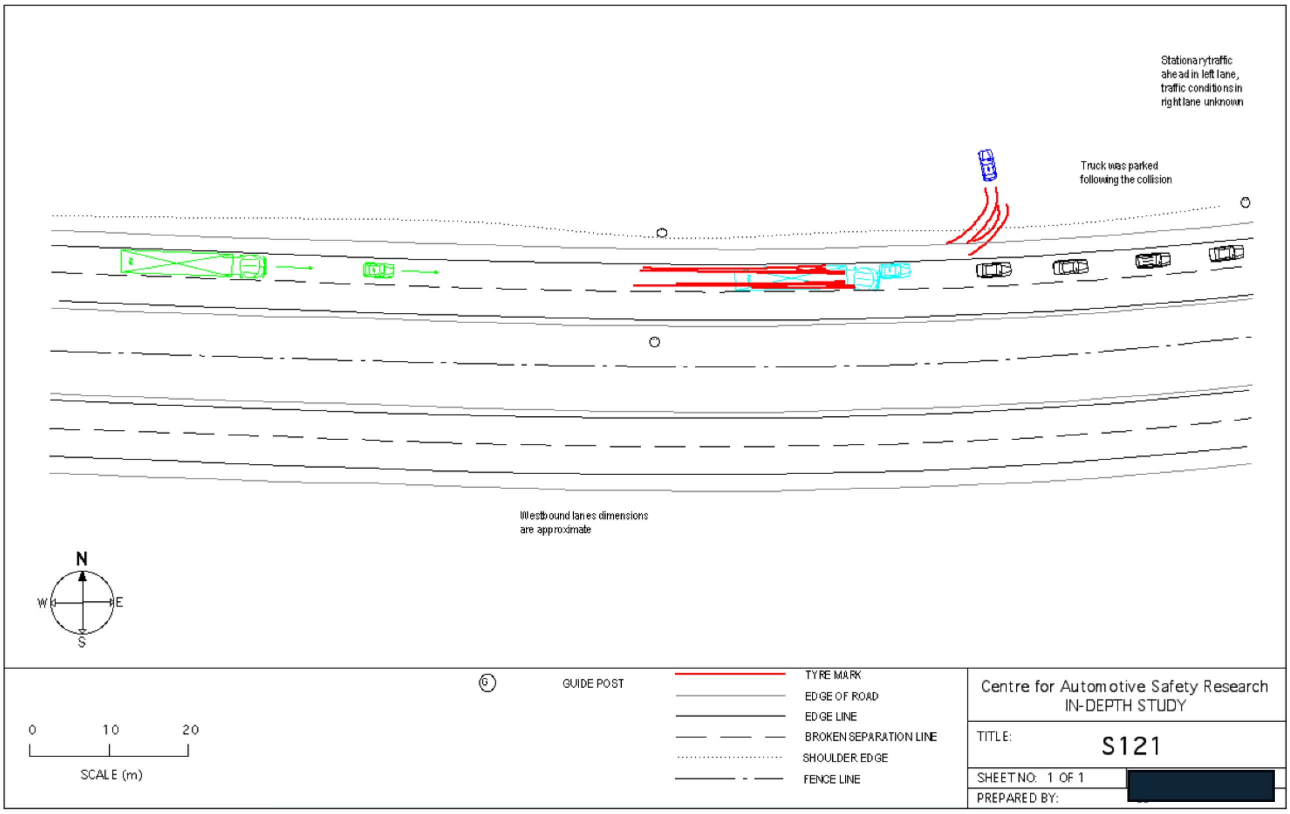
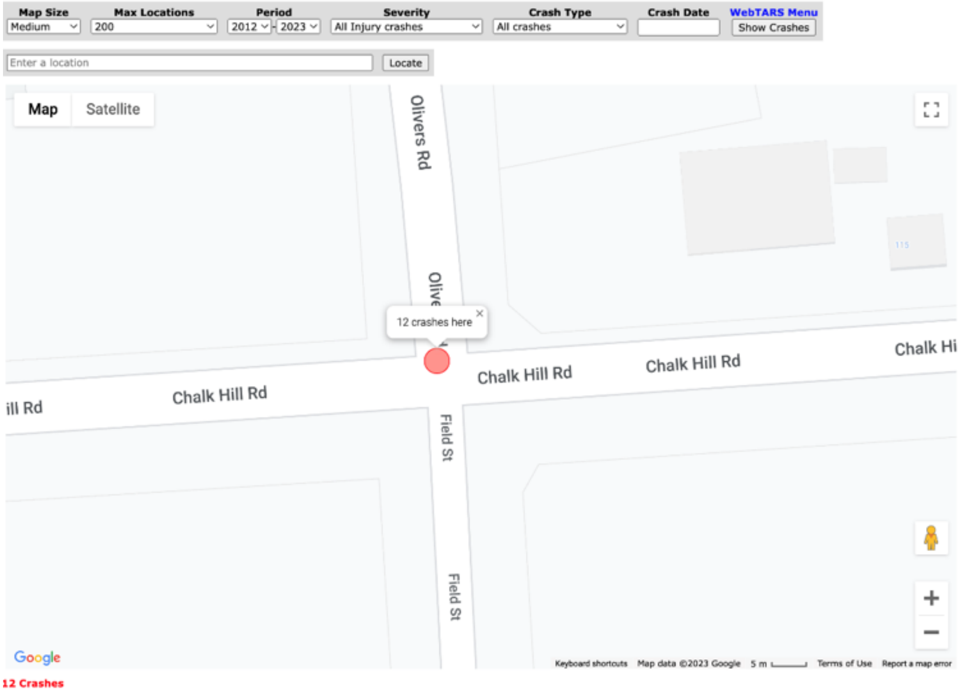


Figure 2.16
Example of a site diagram

2.6.5. Site crash history

CASR’s web-based version of the South Australian Traffic Accident Reporting System (WebTARS) provides the investigators access to historic crash data based on location. This tool allows users to analyse crashes that occurred at the same location. For each crash included in the current study, a 10-year period prior to the crash was considered, and data were collected on the number of previous crashes and the number of previous crashes of the same crash type at that particular location.

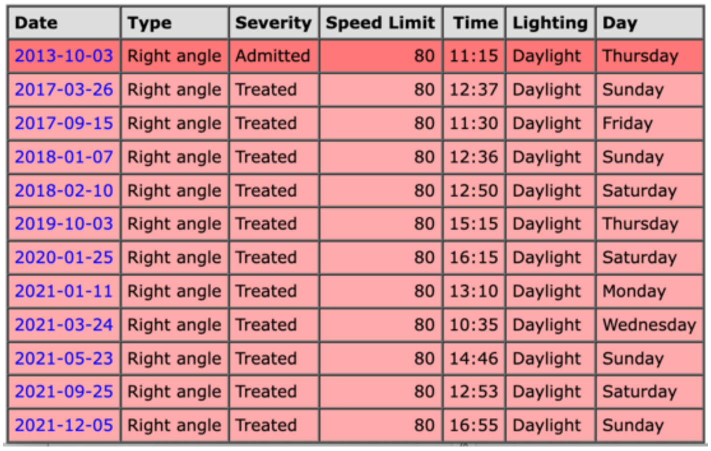
WebTARS features a map visualisation tool that uses density circles to represent the number of crashes at various locations, as shown in Figure 2.17. These density circles allow users to visually identify areas with higher concentrations of crashes. Users can select a circle to access a list of crashes that occurred at the location. The list includes information relating to the date, time, day of week, crash type, severity, speed limit, and lighting conditions of each crash, as shown in Figure 2.18. Each listed crash also includes a hyperlink to the complete de-identified crash record.



Map Size: Medium
Max Locations: 200
Period: 2012 - 2023
Severity: All Injury crashes
Crash Type: All crashes
Crash Date:

12 Crashes

Figure 2.17
Screenshot of the WebTARS database



Date	Type	Severity	Speed Limit	Time	Lighting	Day
2013-10-03	Right angle	Admitted	80	11:15	Daylight	Thursday
2017-03-26	Right angle	Treated	80	12:37	Daylight	Sunday
2017-09-15	Right angle	Treated	80	11:30	Daylight	Friday
2018-01-07	Right angle	Treated	80	12:36	Daylight	Sunday
2018-02-10	Right angle	Treated	80	12:50	Daylight	Saturday
2019-10-03	Right angle	Treated	80	15:15	Daylight	Thursday
2020-01-25	Right angle	Treated	80	16:15	Daylight	Saturday
2021-01-11	Right angle	Treated	80	13:10	Daylight	Monday
2021-03-24	Right angle	Treated	80	10:35	Daylight	Wednesday
2021-05-23	Right angle	Treated	80	14:46	Daylight	Sunday
2021-09-25	Right angle	Treated	80	12:53	Daylight	Saturday
2021-12-05	Right angle	Treated	80	16:55	Daylight	Sunday

Figure 2.18
Table summarising crashes at a given location in WebTARS

2.6.6. Driver / rider crash and traffic offence history

WebTARS also allows the user to search for the crash history of individual drivers using their licence numbers from police reports. Entering a licence number into WebTARS provides a list of the crashes a licensed driver has been involved in that occurred in South Australia and were reported to police. Investigators record the number of prior crashes for each driver, as well as the number in which the driver was deemed by police to be at fault, the number of a similar type to the crash being investigated, and the number of a similar type in which the driver was deemed to be at fault.

The licence number is also entered into the South Australian government Transport Regulation User Management Processing System (TRUMPS) to identify the previous traffic offences of a driver. TRUMPS provides information on the date and type of each offence, which are copied and categorised into groupings of speed, drug, alcohol, moving and administrative (e.g., driving without learner plates displayed) offences.

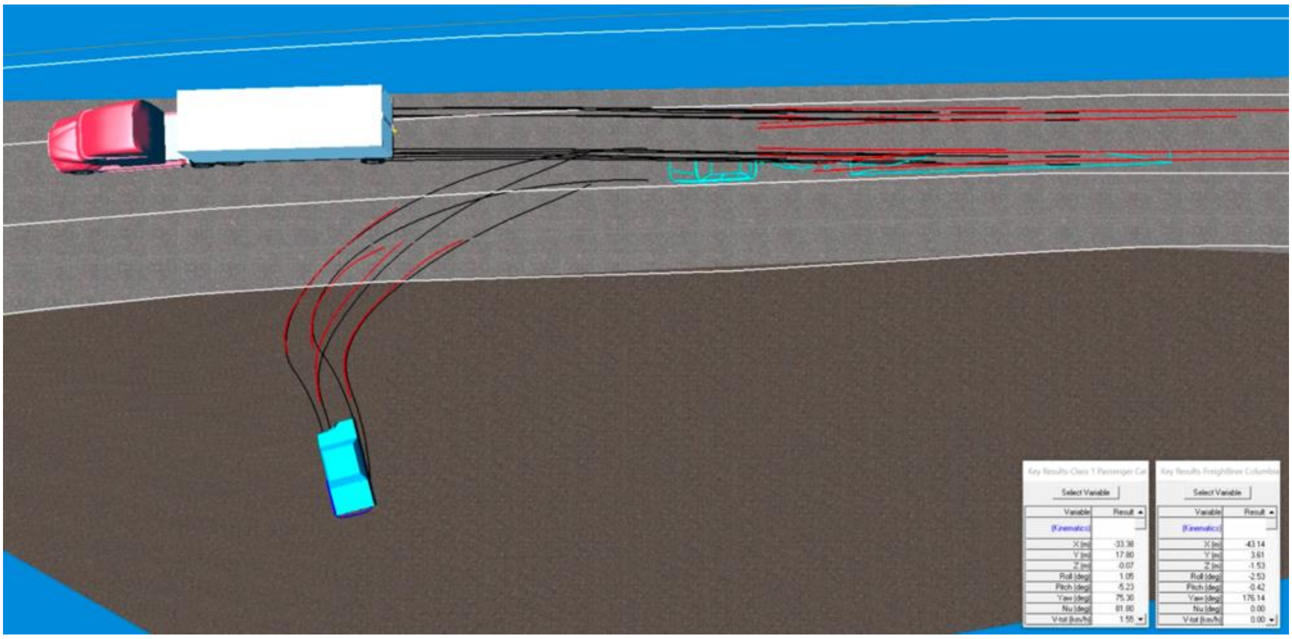
2.6.7. Vehicle specifications

Vehicle specifications not readily identifiable when the vehicle is examined at the crash scene are obtained using online databases. Vehicle specifications are readily available for light vehicles but detailed truck specifications are far more challenging to locate. Specifications for current model trucks can be accessed through manufacturer websites, but even this is complicated by the fact that many safety technologies are optional additions. For older models, some specifications can be ascertained through truck sale websites, but this is complicated by the large number of variants within a certain truck model, and a lack of consistency in the information provided. As a result, the recording of truck specifications was far more reliant on at-scene vehicle examination compared to light vehicle specifications.

2.6.8. Crash reconstruction

The final step of the investigation is to reconstruct the crash. The main purpose of the crash reconstruction is to determine the travel speed, impact speed and change in velocity (delta-*v*) of the vehicles involved in the crash. However, a crash reconstruction can also be used to test the plausibility of different versions of events. CASR reconstructs crashes primarily using the software package known as HVE (Human, Vehicle, Environment) and, more specifically, the SiMoN (Simulation Model Non-Linear) vehicle dynamics model and the DyMESH (Dynamic Mechanical Shell) collision model.

The site diagram that contains the tyre marks, impact positions and final positions of the crash is loaded into HVE, along with the details of the vehicles involved. The crash is then simulated using variations in speed, and in some cases impact configuration, until the simulation closely matches the scene evidence and the damage to the vehicles. Theoretical equations are also used in some situations where they are known to produce accurate results, such as the critical speed equation applied to the curvature of tyre marks in a loss of control crash. If there is insufficient evidence, or the mechanisms involved in the crash are too complex, the crash will not be reconstructed. An image of a crash reconstruction is shown in Figure 2.19.



Key Results-Class 1 Passenger Car

Variable	Result
[Kinematics]	
X [m]	-33.38
Y [m]	17.80
Z [m]	-0.07
Roll [deg]	1.05
Pitch [deg]	-5.23
Yaw [deg]	75.30
Nu [deg]	81.80
V-tot [km/h]	1.55

Key Results-Freightliner Columbi

Variable	Result
[Kinematics]	
X [m]	-43.14
Y [m]	3.61
Z [m]	-1.53
Roll [deg]	-2.53
Pitch [deg]	-0.42
Yaw [deg]	176.14
Nu [deg]	0.00
V-tot [km/h]	0.00

Figure 2.19
An example of a crash reconstruction in HVE
(Black lines are the paths of the wheels in the reconstruction,
while red lines are the actual tyre marks recorded at the scene)

Crash reconstructions can usually be used to calculate reasonable estimates of the impact speed and delta-*v* of the involved vehicles, provided that the impact positions, tyre marks, and final positions are known. However, the calculation of estimated travel speeds has become increasingly more difficult in recent years due to the introduction and uptake of anti-lock braking systems (ABS) in modern vehicles. Calculation of travel speed for crashes in which a vehicle braked prior to impact relies on evidence of braking in the form of a tyre mark. ABS reduces the likelihood that a tyre mark from pre-impact braking will be visible. A tyre mark may also not be present if the driver braked at a level without locking up the wheels. These factors make it more difficult to estimate an accurate travel speed compared to the impact speed of a vehicle involved in a crash.

Calculations unique to truck crashes include truck rollover equations. For this equation, an estimate of the centre of gravity was calculated using the mass of the contents of the truck and the mass of the truck itself. This calculation would produce conservative values for travel and impact speeds, but it does not calculate delta-v.

2.7. Case reviews

Once the investigation is complete (including all further data collection, processing, and analysis) the crash is reviewed by a multidisciplinary panel. The panel consists of experts in human, vehicle and road factors related to road safety and vehicle crashes. Other experts at CASR are included if required, such as those with expertise in medical conditions or driving under the influence. All collected information about a specific crash is presented to the panel by one of the investigators who originally attended the scene. The members of the review panel were consistent for the 68 truck crashes investigated specifically for this study, but there was not complete consistency over the whole sample due to staffing changes over the eight years.

The central purpose of the case review is to identify the factors that contributed to the crash occurring, and interventions that would have prevented or mitigated the crash. Pre-determined lists of contributing factors and interventions are used to guide the review panel, and to ensure that all possible factors and interventions are considered for every case. These lists are not exhaustive and additional contributing factors and interventions can be identified when reviewing a crash. When this occurs, the new contributing factor and/or intervention is added to the lists to be considered for future reviews and its applicability to previously reviewed crashes is also considered. The full lists of contributing factors and interventions are provided in Appendix A.

For the current study, the contributing factors could be assigned to either one of the involved vehicles, or to both. This was done to identify those contributing factors related to the truck, those related to the other road user, and those related to both. Multiple contributing factors could be selected for each crash.

Doecke, Thompson and Stokes (2020, p. 35) further describes the selection of contributing factors by the case review panel:

> “Contributing factors are selected on the basis of all the evidence collected over the course of the investigation. They can never be selected based on mere speculation. Multiple contributing factors can be selected for each crash. While any member of the expert review panel may propose a given contributing factor, experts in the specific area, e.g. human factors, must demonstrate to the group why that factor is or is not relevant in the particular crash. Decisions on human factors rely heavily on interviews with the crash participants and witnesses but statements made by individuals regarding their own behaviour are not taken as fact and are judged against other statements, the evidence from the scene, and the subsequent reconstruction. Road contributing factors are related to road design, operation or condition. Australian Standards and the Austroads’ Guides can be used to support inclusion of these contributing factors; however, adherence to these does not necessarily preclude the factor from contributing. Also, the mere presence of an unsafe road factor does not mean it will be identified as contributing. Vehicle contributing factors are related to vehicle fault (e.g. tyre blowout), condition (e.g. worn tyres), or an inherent quality of a vehicle (e.g. dynamic rollover stability) that contributed to a crash. Determination of vehicle factors relies largely on the physical examination of the vehicle but can also draw upon driver and witness account and scene evidence. It is important to note that contributing factors do not take into account factors that affect the severity of the crash, just the crash occurring in the first place.”

Furthermore, the case review panel is required to write justifications for the selection of the contributing factors. When a contributing factor is closely considered but is ultimately judged by the panel to have not contributed to the crash, a justification is also written for this decision. This is aimed at promoting consistency in a similar manner to case law in the judicial system. The threshold that is used to select a contributing factor would be best described as being above the balance of probabilities used in civil law, but somewhat below the “beyond reasonable doubt” used in criminal law.

Interventions can either be road infrastructure treatments, vehicle technologies, or human behaviour-based interventions. Many of the interventions that are grouped into the road and vehicle categories may be aimed at allowing for, or modifying, human behaviour. However, the human behaviour-based interventions are focused on interventions that do not relate to vehicle technology or road infrastructure, such as enforcement activities. Combinations of interventions can be considered, for example audio tactile lines and sealed shoulder, or frontal airbag and seatbelt pretensioner.

For the present study, a distinction was made between interventions that were truck specific, and those that were either related to the other road user or were general in nature. This was particularly important for vehicle technologies that could apply to a truck or a light vehicle e.g., ESC or AEB. The list of vehicle-based interventions for trucks was largely based on a publication by Transport for NSW titled “Safety features and technologies for heavy vehicles” (Transport for NSW, 2020). There were also some truck-specific road infrastructure treatments included on the list, such as truck-specific barriers or truck lanes on ascents/descents.

The interventions that are selected are also given a confidence level by the review panel. The confidence level is debated by the panel rather than merely being selected by one member. Like contributing factors, all relevant information gathered for a crash is considered when selecting an intervention and the associated confidence level. For example, if lowering the speed limit is selected, it is not assumed that the driver will be compliant. Their compliance with the actual speed limit at the time of the crash is considered, as is their offence history. The level and duration of pre-impact braking in a crash is also considered. Only then can the panel answer the question, “how confident are we that a reduction in the speed limit would have prevented the crash”. If injuries occurred in the crash, the question of whether a speed limit reduction may have mitigated the injuries is also considered. The specific injuries that were sustained are considered and the panel decides how confident they are that any associated reduction in impact severity would reduce the MAIS of at least one person involved in the crash. Mitigating interventions cannot be selected for crashes in which there were no injuries at all, or none that were codable according to AIS.

Cost and practicality were generally not considered when selecting interventions, with two minor exceptions, grade separation and vertical deflection. Grade separating an intersection is a very effective solution for crash prevention but it is very expensive and uses a lot of land. Therefore, it is only selected for intersections between two arterial roads, intersections between an arterial road and a collector road, or rural intersections where at least one road is not a local road. Vertical deflection is used to slow vehicles on the approach to an intersection and was not selected for freeways or controlled motorways.

3. Results

3.1. Data collected

As described in the Method section (Section 2), not all types of information that formed the investigation could be collected in all cases. The types of information that could not be collected for all crashes, vehicles, or participants included hospital data, participant interviews, dashcam footage, fixed camera footage, alcohol and drug test results, and information from EDRs. Furthermore, the speeds of vehicles involved in the crashes could not be determined for all cases. This sub-section provides information on the proportion of the sample for which these types of information could be collected or produced.

3.1.1. Injury data

There were 285 participants (drivers, rider, passengers or pedestrians) involved in the 100 crashes. Of these, it is understood that 126 attended a hospital (based on police reports and interviews), though it was also determined through interviews that 10 of these only attended a hospital to accompany another crash participant, and not for treatment. There were also 14 who died at the scene, meaning that there were a total of 130 participants who were injured to the severity of "hospital treated" or above. Of the 116 participants who were known to have attended hospital for treatment, 62 had their hospital data collected and injuries coded, while nine of the fourteen who died at the scene had their injuries coded from information in the Coroner's file (Table 3.1). A further 15 who attended a hospital from which CASR was not collecting information self-reported injuries that could be AIS coded. This brings the total number of participants with injury to the severity of "hospital treatment" or above, and had their injuries coded with AIS, to 86 (66%).

There were also 39 participants who reportedly had minor injuries that did not require treatment, or injuries for which they saw a GP. Of these, 7 self-reported injuries in an interview, or the nature of their injuries were observed by investigators at scene (Table 3.1).

Table 3.1
Injury data collected for injured crash participants, by source and injury severity level

Injury data source	Hospital treated +		< Hospital treated		Total	
	Number	Percent	Number	Percent	Number	Percent
Hospital	62	48%	-	-	62	37%
Coroner's file	9	7%	-	-	9	5%
Self-reported or observed	15	11%	7	18%	22	13%
None	44	34%	32	82%	76	45%
Subtotal: all sources	**86**	**66%**	**7**	**18%**	**93**	**55%**
Total	**130**	**100%**	**39**	**100%**	**169**	**100%**

3.1.2. Interviews

Participating in an interview is voluntary and interviews can only be conducted after informed consent has been received. Table 3.2 shows how many active participants (drivers, riders, pedestrians) participated in an interview, if they completed the whole interview or not, or if an interview conducted by police was transcribed from the Coroner's report. The data are also separated into the truck drivers, and other active participants (drivers, riders, pedestrians). Table 3.2 also provides information on the reasons that an interview was not conducted. Just under half of the truck drivers were interviewed, while only a third of the other active participants were interviewed. This difference is partly due to a much higher proportion of the other active participants being deceased. Furthermore, there is a larger proportion of the other participants for which an interview was not attempted. Interviews were not attempted when information obtained throughout the investigation indicated that it would be inappropriate to invite them to be involved in this part of the study (e.g., they sustained a serious traumatic brain injury or were in the same vehicle as the person fatally injured). Only 10% of the active participants declined to be interviewed, though this was higher for the truck drivers (12%) than other active participants (7%). The main reason an interview was not conducted was that the active participant could not be contacted (e.g., did not answer phone, SMS, or letter), or a time could not be arranged to conduct the interview after multiple attempts. Truck drivers who did participate in an interview were more likely to only complete a partial interview. Partial interviews were offered to participants who stated they did not have time to complete the full interview.

Table 3.2
Interviews of active participants (driver, rider, pedestrian) conducted
by type of interview, and the reason an interview was not conducted

Crash interview	Truck driver		Other		Total	
	Number	Percent	Number	Percent	Number	Percent
Full	27	26%	23	24%	50	25%
Partial	17	16%	6	6%	23	11%
Coroners	5	5%	2	2%	7	3%
NA - deceased	2	2%	14	15%	16	8%
No contact details	10	9%	8	8%	18	9%
Unable to contact or arrange	27	25%	25	26%	52	26%
Unable to consent	2	2%	2	2%	4	2%
Not attempted	3	3%	9	9%	12	6%
Declined	13	12%	7	7%	20	10%
Subtotal: interviewed	**49**	**46%**	**31**	**32%**	**80**	**40%**
Subtotal: not interviewed	**57**	**54%**	**65**	**68%**	**122**	**60%**
Total	**106**	**100%**	**96**	**100%**	**202**	**100%**

3.1.3. Dashcams and video footage

Video footage of a crash can be highly valuable to an investigation. Table 3.3 shows the number of cases for which dashcam footage was able to be collected as part of the investigations. There were 14 vehicles from which dashcam footage was obtained (out of a total of 198 vehicles), with 13 of these dashcams being mounted to the truck. Note that this does not represent the number of involved vehicles that were fitted with a dashcam, as some could not have their footage collected, and there were also some that were fitted but not operational.

Table 3.3
Dashcam footage collected from the trucks and the other vehicle involved in the truck crashes

Dashcam footage collected	Truck		Other vehicle		Total	
	Number	Percent	Number	Percent	Number	Percent
Yes	13	12%	1	1%	14	7%
No	93	88%	91	99%	184	93%
Total	**106**	**100%**	**92**	**100%**	**198**	**100%**

Video footage was also collected from static cameras owned and operated by the Department for Infrastructure and Transport (DIT), and from private cameras. DIT cameras tend to be placed at intersections but some are also placed on sections of freeways and motorways. Thirteen of the 100 crashes had static camera footage that was collected and reviewed as part of the investigation (Table 3.4). The majority of these (nine) came from DIT, with whom CASR has a formal agreement regarding camera footage, but four came from private cameras. DIT footage could include multiple camera angles.

Table 3.4
Static video footage collected as part of the investigation, by source

Static video camera footage	Number
DIT	9
Private	4
None	87
Total	**100**

3.1.4. EDR data

As discussed in Section 2.5.4, CASR investigators only had the equipment to download EDR data from light vehicles. As there is no regulation in Australia for EDRs, not all vehicles that have an EDR can be accessed and downloaded with a publicly available tool. There were 15 EDR downloads performed as part of the truck crash investigations (Table 3.5). This represents 18% of the involved light vehicles.

Table 3.5
EDR data collected from the trucks and the other vehicle involved in the truck crashes

EDR data collected	Truck		Other vehicle		Total	
	Number	Percent	Number	Percent	Number	Percent
Yes	0	0%	15	18%	15	8%
No	106	100%	77	82%	183	92%
Total	**106**	**100%**	**92**	**100%**	**198**	**100%**

3.1.5. Crash reconstruction and vehicle speeds

Crash reconstructions were performed whenever there was sufficient scene and vehicle evidence, and the mechanisms could be reliably replicated. The key outputs of the reconstructions were vehicle travel speed, impact speed and change in velocity (delta-*v*). EDR data, dashcam and fixed camera footage could also be used as inputs to the reconstruction. Table 3.6 shows the number of vehicles for which these speed indices were determined. Both travel speed and impact speed could be determined for around two-thirds of the vehicles. However, delta-v was only determined for fewer than half of the vehicles. This is largely due to the calculations that can be used to determine travel, and potentially impact, speed for a loss of control or truck rollover not being applicable to the determination of delta-*v*.

Table 3.6
Speed indices determined through reconstruction of the truck crashes

Speed indices determined by crash reconstruction	Truck		Other vehicle		Total	
	Number	Percent	Number	Percent	Number	Percent
Travel speed	66	62%	54	59%	120	63%
Impact speed	73	69%	62	68%	135	68%
Delta-*v*	41	39%	46	50%	87	44%
Total	**106**	**100%**	**92**	**100%**	**198**	**100%**

3.1.6. Alcohol and drug tests

Tables 3.7 and 3.8 show the number of the drivers' and riders' alcohol and drug tests results that were able to be collected as part of the investigations. An alcohol or drug test result not being available may be because it was not conducted at all, or because it could not be conducted at scene due to injury, and the hospital blood test result was not available at the time of writing. While most of the truck drivers had a known alcohol test result, fewer than half had a known drug test result. Truck drivers were almost twice as likely as a driver or rider of other vehicles involved in the truck crashes to have a drug test result available.

Table 3.7
Alcohol test result availability, by vehicle type

Alcohol test result	Truck		Other vehicle		Total	
	Number	Percent	Number	Percent	Number	Percent
Yes	90	85%	70	76%	160	81%
No	16	15%	22	24%	38	19%
Total	**106**	**100%**	**92**	**100%**	**198**	**100%**

Table 3.8
Drug test result availability, by vehicle type

Drug test result	Truck		Other vehicle		Total	
	Number	Percent	Number	Percent	Number	Percent
Yes	51	48%	66	72%	117	59%
No	55	52%	26	28%	81	41%
Total	**106**	**100%**	**92**	**100%**	**198**	**100%**

3.2. The sample and its representativeness

The following section describes the sample in terms of location, day of week, time of day, speed zone, injury severity, crash type, and truck type. To determine the representativeness of the cases collected, comparisons were made to truck crashes reported in the South Australian Traffic Accident Reporting System (TARS). TARS contains information from all police reports on crashes that occur in South Australia. The following criteria were used to select TARS crashes for comparison:

- At least one truck involved
- Minimum crash severity of ‘hospital treated’
- Occurring between 2014 and 2022 (2023 data not yet available)

3.2.1. Location by remoteness area

The locations of the truck crashes by remoteness area, as defined by the Australian Bureau Statistics (ABS, 2016), are shown in Table 3.9. The prevalence of crashes investigated occurring in the major city area was reasonably representative of the population of casualty truck crashes in TARS. However, the geographical restriction of CASR’s crash investigation resulted in the crashes investigated outside of the major city area (Adelaide) being concentrated in inner rural areas. While there were six crashes investigated in outer regional areas (6%), this proportion was much less than the population of truck-involved casualty crashes (17%). No crashes were investigated by CASR in the remote regions of South Australia, where 7% of casualty truck crashes occurred.

Table 3.9
Comparison of in-depth crash investigation sample and
all TARS casualty crashes involving trucks, by remoteness area

Remoteness Area	**In-depth investigations**		**TARS casualty crashes**	
	Number	**Percent**	**Number**	**Percent**
Major City (Adelaide)	57	57%	976	60%
Inner Regional	37	37%	267	16%
Outer Regional	6	6%	284	17%
Remote	0	0%	60	4%
Very Remote	0	0%	41	3%
Unknown	0	0%	1	0%
Total	**100**	**100%**	**1629**	**100%**

Figure 3.1 shows a map of the locations of the truck crashes investigated, and the locations of all casualty truck crashes in South Australia over a similar period. This further highlights that the sample of truck crashes investigated lacks crashes that occur in outer regional and remote areas. The crashes outside the range of the crash investigations appear to predominately occur on major highways between the major cities of Australia, though a number occur on other roads.

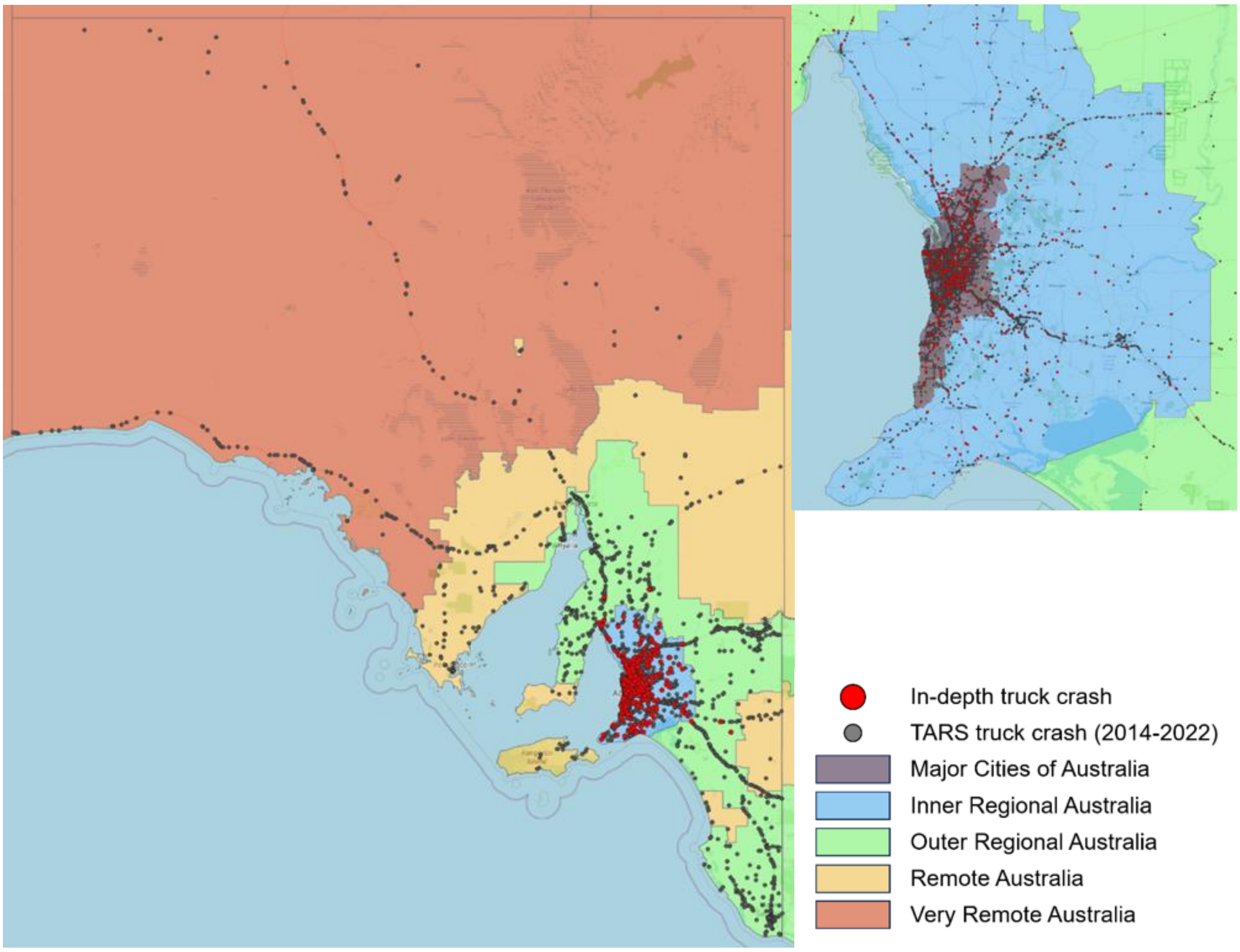


Figure 3.1
Map of South Australia showing the locations of all casualty truck crashes, and the truck crashes investigated by CASR

3.2.2. Day of week and time of day

The distribution of crashes by day of week (see Figure 3.2) in the sample of crashes investigated was reasonably representative of all casualty truck crashes in TARS. However, there was a higher proportion of crashes on Mondays in the in-depth truck crash investigations and slightly fewer on Saturdays. The distribution of crashes by hour of day was also reasonably similar in both datasets, particularly with respect to the on-call periods, especially for the on-call periods spanning 7am to 9pm (see Figure 3.3). However, there were considerably more crashes in the in-depth sample in the 9 am and 3 pm hourly period, and no crashes were investigated that occurred in the period between 11 pm and 6 am when 7% of casualty truck crashes in TARS occurred.

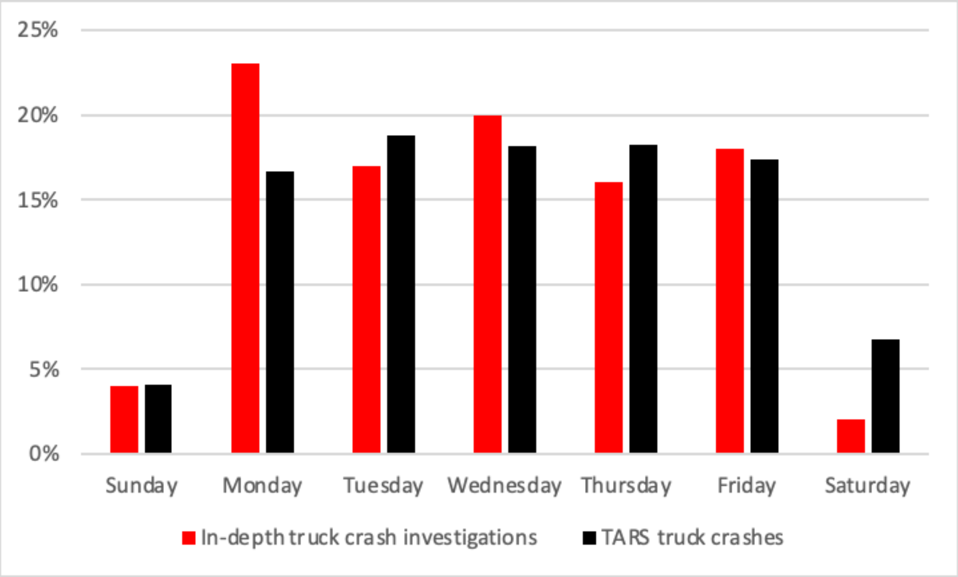


Figure 3.2
Comparison of in-depth crash investigation sample and
all TARS casualty crashes involving trucks, by day of week

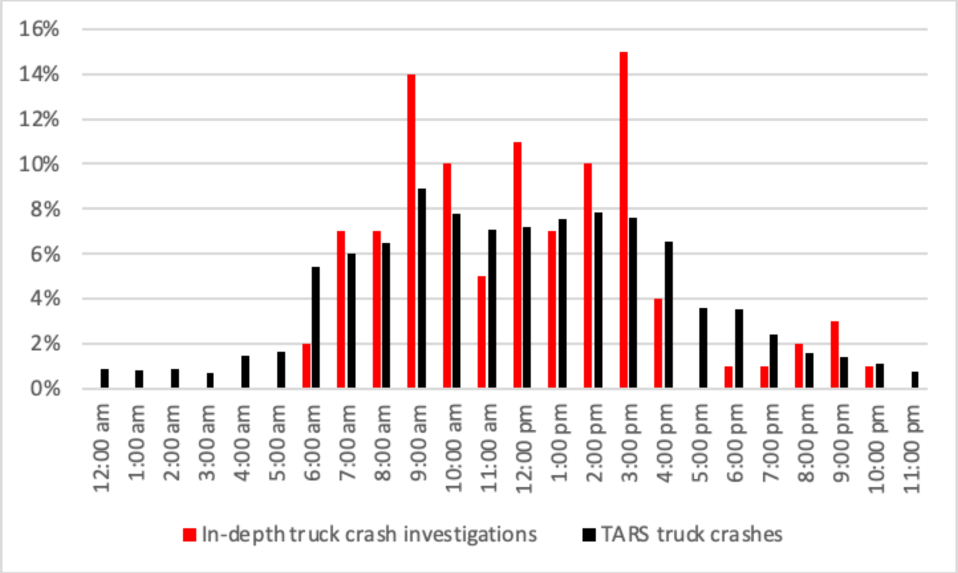


Figure 3.3
Comparison of in-depth crash investigation sample and all TARS casualty
crashes involving trucks, by time of day (note: x-axis labels represent start time of period)

3.2.3. Speed zones

The in-depth truck investigations and TARS truck casualty crashes are shown in Table 3.10, by speed zone. Of particular note is that 60 km/h zones were under-represented in the in-depth crash investigation sample, and 80 km/h zones were over-represented. This may be due to the over-representation of inner regional areas in the sample, with 80 km/h zones being typical of many roads within this area.

Table 3.10
Comparison of in-depth crash investigation sample and
all TARS casualty crashes involving trucks, by speed zone

Speed zone (km/h)	In-depth investigations		TARS casualty crashes	
	Number	Percent	Number	Percent
≤ 40	1	1%	20	1%
50	9	9%	155	10%
60	26	26%	607	37%
70	0	0%	53	3%
80	21	21%	185	11%
90	9	9%	76	5%
100	19	19%	195	12%
110	15	15%	338	21%
Total	**100**	**100%**	**1629**	**100%**

3.2.4. Injury severity

Table 3.11 shows the comparison between the in-depth truck crash investigation sample and TARS casualty truck crashes by police reported injury severity. Fatal crashes were considerably over-represented in the in-depth crash investigations. Table 3.11 also highlights how some crashes were investigated due to their potential for injury (rollover or high speed-limit) rather than meeting the criterion of ambulance transport that would generally ensure they are classified as a casualty crash in the police report. However, it should also be noted that police reported injury level is not always accurate, as it appears often to be based on an initial estimate at the scene. There were several instances in which participants in crashes investigated by CASR were transported by ambulance to hospital, yet were listed as non-injury or minor injury in the police report. It is also worth noting that the hospital admission definition used by police is based on a hospital stay of 24 hours.

Table 3.11
Comparison of in-depth crash investigation sample and
all TARS casualty crashes involving trucks, by injury severity

Injury severity	In-depth investigations		TARS casualty crashes	
	Number	Percent	Number	Percent
Non-injury	12	12%	0	0%
Doctor / minor injury	7	7%	0	0%
Hospital treated	44	44%	1207	74%
Hospital admitted	19	19%	289	18%
Fatal	18	18%	133	8%
Total	**100**	**100%**	**1629**	**100%**

3.2.5. Crash types

The crash types of the sample of truck crashes investigated and the TARS truck casualty crashes are shown in Table 3.12. Rear end crashes were the most common crash type in the sample of crashes investigated, as in TARS, though they were under-represented in the in-depth crash investigations. Right angle and single vehicle not into object (usually rollover) crashes were the next most common in the in-depth crash investigations. Single vehicle not into object crashes were over-represented, as was expected due to the sampling design. However, the over-representation of right-angle crashes was not expected. This may be a result of the over-representation of inner regional areas and the corresponding road network layout comprising of many intersections, which may increase the likelihood of right-angle crashes occurring. The other crash type that was considerably over-represented in the sample was U-turn in front crashes, with the sample seemingly capturing one-quarter of such casualty crashes involving trucks over the time period.

Table 3.12
Comparison of in-depth crash investigation sample and
all TARS casualty crashes involving trucks, by crash type

Crash type	**In-depth investigations**		**TARS casualty crashes**	
	Number	**Percent**	**Number**	**Percent**
Rear end	21	21%	436	27%
Right angle	15	15%	105	6%
Single vehicle not into object	15	15%	149	9%
Side swipe	8	8%	215	13%
Head-on	9	9%	155	10%
Right turn - opposite	8	8%	91	6%
Right turn - adjacent	5	5%	88	5%
U-turn in front	5	5%	18	1%
Single vehicle into object	5	5%	122	7%
Pedestrian	4	4%	50	3%
Hit parked vehicle	0	0%	56	3%
Other	5	5%	144	9%
Total	**100**	**100%**	**1629**	**100%**

3.2.6. Truck types

Table 3.13 shows the types of trucks that were present in the in-depth sample and the comparative TARS sample. TARS uses much broader truck classifications than the in-depth sample, meaning comparison could only be made by aggregating classifications to form categories that appeared to be equivalent. Light rigid trucks (less than 4.5 tonne) appear to be under-represented in the sample, while articulated trucks with a single trailer appear over-represented. It is unclear how reliable the truck classification variable in TARS is. As a result of this, and the broad classifications use in TARS, the exact representativeness of the sample in terms of truck types is difficult to know. The trucks involved in the crashes investigated ranged from a gross vehicle mass of 4.2 tonne to a gross combination mass of 130 tonne.

Table 3.13
Comparison of in-depth crash investigation sample and
all TARS casualty crashes involving trucks, by truck type

Truck type	**In-depth investigations**		**TARS casualty crashes**	
	Number	**Percent**	**Number**	**Percent**
Prime Mover only	1	1%	-	-
2-Axle Rigid Truck <4.5 tonne	3	3%	-	-
2-Axle Rigid Truck >4.5 tonne	28	26%	-	-
3-Axle Rigid Truck	13	12%	-	-
4-Axle Twinsteer Truck	5	5%	-	-
5-Axle Semi-trailer	4	4%	-	-
6-Axle Semi-trailer	30	28%	-	-
3-Axle Truck and 2-Axle Dog Trailer	1	1%	-	-
3-Axle Truck and 3-Axle Dog Trailer	3	3%	-	-
3-Axle Truck and 4-Axle Dog Trailer	3	3%	-	-
7-Axle B-double	1	1%	-	-
9-Axle B-double	11	10%	-	-
11-Axle A-double	1	1%	-	-
12-Axle B-triple	1	1%	-	-
14-Axle AB-triple	1	1%	-	-
Subtotal: Rigid <4.5 tonne	**3**	**3%**	**166**	**10%**
Subtotal: Rigid >4.5 tonne	**46**	**43%**	**773**	**45%**
Subtotal: Articulated, 1 trailer	**41**	**39%**	**489**	**29%**
Subtotal: Articulated, >1 trailer	**15**	**14%**	**283**	**17%**
Total	**106**	**100%**	**1711**	**100%**

3.3. Contributing factors

3.3.1. All crashes investigated

The contributing factors that were identified in the crashes investigated and their prevalence are shown in Table 3.14. The contributing factors are shown according to which road user they were related to: the truck or the other road user. The same contributing factor could relate to both the truck and the other road user. For this reason, the values shown for the crash in Table 3.14 are not necessarily the sum of the numbers for the trucks and the other vehicles for each contributing factor.

There were 50 unique contributing factors identified, with an average of 2.3 contributing factors identified per crash, and no single contributing factor was present in more than 15% of the cases. There were more contributing factors relating to the trucks than the other road users, most likely because 20 of the 100 crashes were single truck crashes. Human factors were the most common type of contributing factor, with 88 of the crashes involving at least one contributing human factor. Road related factors contributed to 43 of the crashes, and vehicle factors to 30. The two most common contributing factors, “human: speed too high for the conditions” and “vehicle: dynamic stability” were generally related to truck rollovers. Exceeding the speed limit was also a common contributing factor, and was relatively evenly split between trucks and the other road users involved in the truck crashes.

Other human factors of particular relevance for truck crashes were fatigue and drug use. There were four crashes in which fatigue on the part of the truck driver was judged by the review panel to have contributed to the crash. None of these cases involved long distance trucking. In two cases, the fatigue was attributable, at least in part, to the hours of work the drivers were being required to drive and general pressure from their company. There were a further three in which the other road user's fatigue contributed to the crash. Regarding drug use contributing to the truck crashes, it is notable that drug use on the part of the truck driver was not judged to have contributed to any of the crashes. There were two crashes in the sample in which the truck driver tested positive for drugs but it was not judged to have contributed to the crash in either case. In one case, this was because the truck was stationary for some time before it was impacted in the rear by a light vehicle. In another case, the positive drug test was reportedly due to medical cannabis use, and while still illegal, it could not be confidently ascertained that this contributed to the crash.

Visibility was the most common road related contributing factor, and this was a frequent issue for both trucks and other road users. This was typically a contributing factor for crashes at junctions but could contribute to head on crashes as well. The second most common road related contributing factor was "unexpected road or traffic conditions". In the context of truck crashes, this included trucks that were moving particularly slowly on high-speed roads due to steep ascents or manoeuvring (e.g., tight turn into a farm gate). The width of the road was also a common road related contributing factor for the truck crashes. Such crashes typically involved narrow winding roads through the hills surrounding Adelaide where visibility of oncoming traffic can also be an issue. These crashes resulted in head-on crashes, rear end or side-swipe crashes involving vulnerable road users, and a single truck rollover.

A blind spot was the second most common contributing factor related to the vehicle. In all six of these crashes, it was the blind spot(s) of the truck, and not the other involved vehicle, that contributed to the crash occurring. Blind spots contributed to truck drivers failing to see approaching vehicles or pedestrians at junctions, or vehicles in the lane next to them prior to a lane change manoeuvre. Brake issues were also exclusively related to the trucks involved in the crashes, though only three brake issues could be identified (see Section 2.5.4 regarding difficulties identifying truck brake issues).

Table 3.14 (Part 1)
Contributing factors of all crashes investigated, by the unit they were associated with, and for the crash as a whole

Contributing factor	Truck	Other	Crash
Human: speed too high for conditions	14	1	15
Vehicle: dynamic stability	14	0	14
Human: exceed speed limit	7	6	13
Road: visibility	8	5	11
Human: fail to give way unspecified	3	8	11
Human: fail to check for traffic	2	8	10
Road: unexpected road or traffic conditions	4	5	9
Human: misjudgement	3	6	8
Road: road layout	5	3	8
Human: unfamiliarity with road	4	4	8
Human: fail to adequately check for traffic	5	2	7
Human: fatigue	4	3	7

Note: contributing factors can apply to both units in a crash

Table 3.14 (Part 2)
Contributing factors of all crashes investigated, by the unit they were associated with, and for the crash as a whole

Contributing factor	Truck	Other	Crash
Road: road width	4	4	6
Human: disobey traffic signal	3	4	6
Vehicle: blind spot	6	0	6
Human: medical condition	0	6	6
Vehicle: conspicuity	1	4	5
Road: weather conditions	2	2	5
Human: unknown	3	2	5
Human: unfamiliarity with vehicle	4	0	4
Human: recognition failure	3	1	4
Human: distraction	2	2	4
Human: competing demands for attention	0	4	4
Human: drugs (illicit)	0	4	4
Human: incorrect positioning	2	1	3
Road: road surface	3	0	3
Road: vertical alignment	3	0	3
Road: wet road	3	0	3
Vehicle: brakes	3	0	3
Vehicle: other	3	0	3
Human: other	2	1	3
Human: unsafe overtaking	1	2	3
Road: unsealed shoulder	1	2	3
Human: inexperience	0	3	3
Road: horizontal alignment	2	1	2
Human: inattention	2	0	2
Road: superelevation	2	0	2
Human: impulsive decision	0	2	2
Road: large roadside drop off	1	1	2
Road: signage	1	1	2
Human: peer effects	0	2	2
Human: suicide	0	2	2
Road: obstacle on road	1	0	1
Road: road marking	1	0	1
Vehicle: overload	1	0	1
Vehicle: tyre blowout	1	0	1
Vehicle: tyre low tread depth	1	0	1
Human: alcohol	0	1	1
Road: roadworks	0	1	1
Total	**137**	**101**	**233**

3.3.2. Serious injury cases: (hospital admission and fatal)

Table 3.15 shows the contributing factors for crashes in which at least one participant was admitted to hospital or died as a result of the crash. Note that this is based on CASR’s definition of hospital admission as a length of stay of 4 hours or more, which differs from the definition used in police reports (24 hours or more). The contributing factors associated with truck rollover (vehicle: dynamic stability and human: speed too high for conditions) still ranked highly and contributed to a similar percentage of the crashes. The dynamic stability of the truck remained the top contributing factor associated with the trucks. The layout of the road was the top contributing factor relating to the road and environment. This is a somewhat broad contributing factor that generally relates to the design and/or location of a junction. For example, two of the crashes in which the road layout was judged to have contributed to the crash involved junctions positioned on, or at the conclusion of, a long descent. Further examples include unsignalised seagull junctions, and junctions with poor approach angles.

A variety of human factors contributed to the serious injury crashes, and these also varied by which road user made the error, the truck driver or the other road user. It is concerning that the most common human contributing factors for truck drivers were both related to speed: exceeding the speed limit and speed too high for the conditions. Note that these contributing factors were not selected when brake issues contributed to a truck exceeding the speed limit or travelling at a speed too high for the conditions. It is also concerning that disobeying a traffic signal ranked so highly as human error made by the truck driver. Again, if the truck driver disobeyed a traffic signal due to brake issues, this contributing factor was not selected. Two human factors associated with failing to give way at a junction, fail to adequately check for traffic and recognition failure, also ranked highly for truck drivers.

Table 3.15 (Part 1)
Contributing factors of serious injury (hospital admitted and fatal) crashes investigated (n=50), by the unit they were associated with, and for the crash as a whole

Contributing factor	Truck	Other	Crash
Vehicle: dynamic stability	6	0	6
Road: road layout	4	2	6
Human: disobey traffic signal	3	4	6
Human: fail to give way unspecified	1	5	6
Human: fail to check for traffic	0	6	6
Human: exceed speed limit	4	1	5
Human: speed too high for conditions	4	1	5
Road: visibility	2	4	5
Human: unfamiliarity with road	2	3	5
Human: fail to adequately check for traffic	3	1	4
Vehicle: conspicuity	1	3	4
Human: recognition failure	3	0	3
Road: road width	2	3	3
Human: distraction	2	1	3
Human: other	2	1	3
Human: misjudgement	1	3	3
Human: fatigue	1	2	3
Road: unexpected road or traffic conditions	1	2	3
Human: medical condition	0	3	3
Road: weather conditions	0	2	3

Table 3.15 (Part 2)
Contributing factors of serious injury (hospital admitted and fatal) crashes investigated (n=50), by the unit they were associated with, and for the crash as a whole

Contributing factor	Truck	Other	Crash
Human: incorrect positioning	2	0	2
Human: unfamiliarity with vehicle	2	0	2
Road: road surface	2	0	2
Road: vertical alignment	2	0	2
Vehicle: blind spot	2	0	2
Vehicle: brakes	2	0	2
Human: unknown	1	1	2
Human: unsafe overtaking	1	1	2
Road: unsealed shoulder	1	1	2
Human: competing demands for attention	0	2	2
Human: drugs	0	2	2
Human: suicide	0	2	2
Road: horizontal alignment	1	0	1
Road: large roadside drop off	1	0	1
Road: superelevation	1	0	1
Vehicle: other	1	0	1
Vehicle: overload	1	0	1
Vehicle: tyre blowout	1	0	1
Human: alcohol	0	1	1
Human: inexperience	0	1	1
Human: peer effects	0	1	1
Road: signage	0	1	1
Total	**63**	**60**	**119**

3.4. Interventions for crash prevention and mitigation

The case review panel selected interventions believed to have the potential to prevent or mitigate a crash, along with a level of confidence (low, moderate, high) in the selected intervention's ability to prevent or mitigate the crash in question. There was a total of 119 unique interventions that could have prevented at least one crash at any level of confidence. On average, each crash had 4.7 interventions identified, 1.8 with a high level of confidence in their ability to prevent the crash, 1.3 with a moderate level of confidence, and 1.6 with a low level of confidence. Only one of the 100 crashes had no interventions identified, while a further three had interventions for which the review panel only had a low level of confidence in their ability to prevent or mitigate the crash.

Table 3.16 shows the number of crashes in the sample each of the top 25 interventions could have prevented with at least a moderate level of confidence. Interventions specific to the trucks are highlighted with the word "Truck" preceding the description of the intervention. The top three interventions for crash prevention are all road infrastructure interventions for junctions. The top three vehicle technology interventions were all related to the truck; truck ESC, truck AEB, and trailer roll stability systems. A blind spot elimination system was another crash prevention technology for trucks that was within the top 25 prevention interventions. AEB for the other vehicle also ranked highly, as did Lane Keep Assist.

Table 3.16
The top 25 prevention interventions for all crashes investigated (n = 100)

Intervention	Number
Roundabout	31
Traffic lights	23
Grade separated junction	19
Truck: Electronic Stability Control (ESC)	12
Prevent right turn	10
Speed limit reduction (20 km/h max)	10
Apprehension for drink/drug driving offence	9
Truck: Autonomous Emergency Braking (AEB)	9
Truck: Trailer roll stability system	8
Vertical deflection	8
AEB	7
Apprehension for speed offence	7
Truck: Adaptive Cruise Control (ACC)	7
Widen road	6
Improved geometry of junction	5
Improved sight distance	5
ISA - Limiting	5
Lane Keep Assist (LKA)	5
Single lane of traffic	5
Adaptive Cruise Control (ACC)	4
Apprehension for unlicensed driver	4
Controlled right turn (signalised intersection)	4
Sealed shoulders	4
Truck: Blind spot elimination system	4

Table 3.17 shows the top interventions that could have prevented the crashes that resulted in at least one participant being admitted to hospital or killed (n=50). Only interventions that were selected with a moderate level of confidence were counted. As there were many interventions selected for same number of crashes (two) the top 29 are shown rather than the top 25, as in Table 3.16. The top interventions are broadly similar to the whole sample, though speed limit reduction was less commonly selected. More truck technologies are present in the top interventions for serious injury crashes than for the whole sample, though many of these technologies were predicted by the review panel to have prevented only two of the 50 serious crashes.

Table 3.17
The top 29 prevention interventions for serious injury
(hospital admitted and fatal) crashes investigated (n=50)

Interventions	Number
Roundabout	15
Grade separated junction	12
Traffic lights	12
Prevent right turn	8
Truck: Electronic Stability Control (ESC)	5
Improved geometry of junction	4
Truck: Trailer roll stability system	4
Vertical deflection	4
Apprehension for drink/drug driving offence	3
Apprehension for speed offence	3
Improved sight distance	3
Lane Keep Assist	3
Pedestrian/cyclist over/underpass	3
Sealed shoulders	3
Widen road	3
Audio tactile centre lines	2
Controlled right turn (signalised intersection)	2
Improved road surface (remove undulations and defects)	2
ISA - Limiting	2
Lane Departure Warning	2
Narrow centre median (1m) + audio tactile centre lines	2
Speed limit reduction (20 km/h max)	2
Truck: Adaptive Cruise Control (ACC)	2
Truck: Autonomous Emergency Braking (AEB)	2
Truck: Blind spot elimination system	2
Truck: Collision Warning	2
Truck: high performance brakes	2
Wide centre median (5m+)	2
Single lane of traffic	2

Interventions were also identified that have the potential to mitigate the crash. For a full definition of how crash mitigation was defined, see Section 2.7. A confidence level was also selected for each mitigating intervention. There was a total of 60 unique interventions selected that could have mitigated at least one crash at any level of confidence. On average each crash had 1.9 mitigating interventions identified per crash, 0.4 with a high level of confidence in their ability to mitigate the crash, 0.6 per crash with a moderate level of confidence, and 0.8 with a low level of confidence. It should be noted that some interventions could be selected under both crash prevention and mitigation, often at different levels of confidence.

The top 20 interventions selected by the review panel with a medium or high confidence to mitigate the crash are shown in Table 3.18. A speed limit reduction of up to 20 km/h was the most common mitigation intervention selected, having also been found to have strong potential for crash prevention. Vertical deflection, a physical means of reducing speed at junctions, was the second most commonly selected. The most common truck specific mitigation intervention was increased cabin strength. This generally related to single vehicle truck crashes but was also selected for one head-on crash. Other truck specific mitigation interventions that featured in the top 20 were ABS, a driver's airbag (frontal), a curtain airbag, a collision warning system, electronic braking system, side under-run protection, and a truck-specific centre barrier. The sole human-based mitigation intervention within the top twenty mitigation interventions, wearing of a seatbelt, was only applicable to the truck drivers.

Table 3.18
The top 20 mitigation interventions for all crashes investigated (n=100)

Interventions	Number
Speed limit reduction (20 km/h max)	15
Vertical deflection	10
Centre barrier	6
Curtain airbag	6
Rural Junction Active Warning Sign (RJAWS)	5
Roundabout	4
Side airbag	4
Truck: Increased cabin strength	4
AEB	3
Truck: Antilock Braking Systems (ABS)	3
Truck: frontal airbag (driver)	3
Collision Warning	2
ISA - Limiting	2
Side intrusion protection	2
Truck: Collision Warning	2
Truck: Curtain airbag	2
Truck: Electronic Braking System (EBS)	2
Truck: Side under-run protection	2
Truck: truck specific centre barrier	2
Wearing of seatbelt	2

Table 3.19 shows the top 15 interventions that could have mitigated the outcome of the serious injury crashes with a medium to high level of confidence. Only 15 are shown, as there were a further 18 that could have mitigated only one crash. The top interventions remained the same. Notable changes between the top mitigating interventions for all crashes and those for serious injury crashes include the absence of truck ABS, collision warning and EBS. These truck technologies could have mitigated two to three of the crashes in overall sample. Collision warning and limiting ISA for the other involved vehicle were also top mitigating interventions for the overall sample (Table 3.18) but were not in the top mitigating interventions when only the serious injury truck crashes were considered (Table 3.19).

Table 3.19
The top 15 mitigation interventions for serious injury
(hospital admitted and fatal) crashes investigated (n=50)

All interventions	Number
Speed limit reduction (20 km/h max)	12
Vertical deflection	7
Centre barrier	5
Curtain airbag	5
Rural Junction Active Warning Sign (RJAWS)	4
Side airbag	4
Truck: Increased cabin strength	4
AEB	3
Roundabout	3
Side intrusion protection	2
Truck: Curtain airbag	2
Truck: Driver's airbag	2
Truck: Side under-run protection	2
Truck: Truck specific centre barrier	2
Wearing of seatbelt	2

4. Discussion

The investigation, analysis, and multi-disciplinary reviews of 100 truck crashes revealed a wide range of factors that contributed to the crashes occurring, with the most common contributing factor still only present in 15% of the crashes. Human factors contributed to most of the crashes (88%), consistent with a prior study on crashes conducting using similar methodology, but not focussed on trucks (Doecke, Thompson & Stokes, 2020), and the US Large Truck Crash Causation Study (Federal Motor Carrier Safety Administration, 2007). However, vehicle factors were far more prevalent in the current study on truck crashes than in the study of crashes in general by Doecke, Thompson & Stokes (2020). In the present study, 30% of the crashes had at least one vehicle factor that contributed to its occurrence, compared to 16% in Doecke, Thompson & Stokes (2020).

4.1. Contributing factors

4.1.1. Dynamic stability of trucks

The dynamic stability of the truck was the most common contributing factor for both the complete sample and the crashes that resulted in hospital admission or fatality. This suggest that this was not merely a product of the sample design, which allowed non-injury truck rollovers to be investigated. A loaded truck can have far less dynamic stability than even the least stable light vehicle. The dynamic stability of a truck can be further reduced by unevenly distributed loads or loads that are allowed to shift. Light vehicles are designed so that they cannot rollover by simply entering a turn too fast, even at the maximum side force that can be generated by the tyres. In contrast, a loaded truck may begin to rollover at less than half the maximum side force of the tyres (Sutphen & Varner, 2003). Furthermore, articulated trucks may give no warning to the driver that the rollover threshold of the vehicle is being approached or exceeded until it is well past the point of no return. When a truck rolls over without contact with another vehicle the truck driver has generally made an error in the speed at which they navigated the turn. However, the lack of warning and feedback to the driver that they are entering a corner at speed at which the truck will rollover means they are, in some sense, being set up to fail. It is hard to imagine a modern light vehicle being allowed to be designed in such a way.

Rollover crashes have a high potential for injury as the truck and its load become large, uncontrolled projectiles and may come into contact with other vehicles or pedestrians. Furthermore, if the truck rolls onto the driver’s side, or rolls more than a quarter turn, the cabin may not be able to withstand the impact or static forces acting upon it. Unrestrained truck drivers are also at particular risk of serious injury in a truck rollover.

4.1.2. Speed

Speed was also a common contributing factor, both speed too high for the conditions, and exceeding the speed limit. Speed too high for the conditions was commonly associated with a truck rollover. Exceeding the speed limit had a similar prevalence for trucks and the other vehicle in the whole sample but, when only the higher severity crashes were considered, it was much more likely to be the truck that was speeding. This is perhaps reflective of the increased aggressivity of trucks (Budd, Newstead & Watson, 2021); a truck that is speeding has a larger influence on the injury severity of a crash than a light vehicle. The trucks that were speeding tended to be doing so in speed zones below 100 km/h. This may be partly due to heavy trucks in Australia being electronically limited to

100 km/h. However, trucks were also found to be speeding in 100 km/h zones on downgrades, where this electronic limiter would not be able to restrict the truck's speed. It is worth noting that travel speeds could only be determined in around 60% of the crashes. This means that it is possible that the prevalence of exceeding the speed limit could be considerably higher than could be confidently identified in the investigations.

4.1.3. Failure to give way

Human errors associated with failing to give way at a junction were also common factors that contributed to the truck crashes investigated. In a number of cases the human error could not be identified due to the driver who made the error not participating in an interview. When the contributing factor could be identified, it was found that truck drivers were most likely to fail to check for traffic adequately, while the drivers of the other vehicles were most likely to fail to check for traffic altogether. Failure to adequately check for traffic reflects cases in which a driver has looked for traffic but has failed to do so either for long enough, or thoroughly enough, to perceive an approaching vehicle that may have been momentarily or partially obscured, or may have been difficult to perceive with a quick look. Visual obstruction in these cases may come from within the vehicle (blind spot), from the roadside, or from another vehicle on the through road. A failure to check for traffic is generally due to a driver failing to recognise that they had to give way, or that they were even approaching an intersection (Stokes & Woolley, 2022).

Disobeying a traffic signal can also be considered a failure to give way at a junction. It is concerning that disobeying a traffic signal ranked so highly among the factors that contributed to the serious injury crashes. In the cases in which the truck driver disobeyed the traffic signal (n=3), one resulted in a fatality while another resulted in very serious injuries (MAIS 5) that required a prolonged period of hospitalisation and ongoing care. Furthermore, in two of these cases the driver of the truck had at least two prior red light running offences within the last three years. While any vehicle that fails to obey a traffic signal is putting other road users at risk, a truck doing so presents a particularly high risk due to their aggressivity.

4.1.4. Blind spots in trucks

A blind spot within the truck was one of the more common contributing factors (n=6). Blind spots in trucks can be substantial due to a combination of the height of cabin and, in the case of non-cabover designs, the length of the nose or bonnet. Large mirrors and cabin pillars can also cause blind spots. Blind spot diagrams produced by a building company showed that the blind spots for a truck driver can be quite large and can vary greatly from truck to truck (Hanson, 2020). Blind spots can greatly increase the risk associated with a lane change manoeuvre and contribute to side swipe crashes that often cause the other vehicle to spin out of control, a highly hazardous condition. Additionally, they can contribute to the truck driver failing to give way at an unsignalised intersection when combined with a failure to adequately check for traffic. In the sample investigated for this study, blind spots contributed to crashes involving both lane change manoeuvres and failing to give way at an intersection.

4.1.5. Drugs and Fatigue

None of the 100 crashes had drug use by the truck driver as a contributing factor. While there were two truck drivers who tested positive for drugs, it was judged that the drug use did not contribute to either crash. Unlike alcohol tests, drug tests are not conducted for all drivers involved in crashes. Just over half of the drivers did not have a drug test result available so it is possible that the actual prevalence of drug use amongst truck drivers involved in crashes is higher than was found in this study. The under-representation of outer regional and remote crashes in the sample may have also contributed to an underestimate of the prevalence of drug driving as a contributing factor.

There were seven crashes in which fatigue was a contributing factor, with three of these being due to the fatigue of the truck driver. However, this may be an under-representation of the true prevalence of fatigue as a contributing factor in truck crashes. Recent research (Thompson & Wundersitz, in press) has shown that the involvement of fatigue in a crash is often difficult to identify. Furthermore, the lack of crashes in the sample occurring in the outer regional and remote areas of South Australia, and between the hours of 9 pm and 6 am, may have contributed to an underrepresentation of fatigue as a contributing factor. Gibson (2022) found that truck driver fatigue contributing to a crash was most prevalent in outer regional areas and during the hours of 12am to 6am, based on insurance investigations of crashes with losses over $50,000 (Gibson, 2022). While the sampling criterion for the crashes reported on by Gibson (2022) is vastly different to the present study, and insurance investigation could not be described as “no blame”, this does support the idea that fatigue is likely to be under-represented in the present sample. There are strong laws aimed at reducing fatigue for certain types of truck driving under the National Heavy Vehicle Law, but the requirements to fill out work diaries do not extend to drivers operating within 100 km of their base, though rules regarding maximum work and minimum rest hours still apply. Two of the truck drivers involved in crashes in which fatigue was identified as a contributing factor were not legally required to fill out a work diary but did feel that they were under pressure with regard to working hours and taking breaks.

4.2. Interventions

4.2.1. Road-based interventions at junctions

The results indicate that the greatest potential to prevent crashes involving trucks is in road-based interventions focussed on intersections. The particular interventions include roundabouts, the installation of traffic lights (with fully controlled right turns), grade separating junctions, preventing right turns, vertical deflection, and improving the geometry of the junction. All these treatments are aimed at either reducing the complexity of the decisions the driver has to make, eliminating conflicts, reducing the speed through the intersection, or a combination of these. None of these interventions are truck specific in the sense that their implementation to account for trucks must be fundamentally different. However, adequate space for turning trucks must be considered at all junctions, commensurate with the types of trucks permitted on a given road. This finding is consistent with those of Doecke, Thompson & Stokes (2020), who identified the top prevention interventions for a sample of crashes in SA not focussed on trucks. This suggests that implementing the top infrastructure interventions to prevent crashes at intersections found in both this study and Doecke, Thompson & Stokes (2020) will prevent a considerable number of crashes involving trucks, as well as those that do not involve a truck.

Centre barriers were found to be an important intervention for crash mitigation. A centre barrier that retains the vehicle impacting it can prevent that vehicle colliding head-on with vehicles travelling in the opposing direction or prevent the vehicle leaving the right side of the road and colliding with roadside hazards. Centre barriers not specifically designed to retain a truck were found to mitigate more crashes than those that were designed for truck impacts, reflecting the fact that it was more frequent that the other vehicle crossed the centreline. When both types of centre barrier are considered, they were found to mitigate 8% of all the crashes, and 14% of the high severity crashes. This is consistent with research that has shown that a head-on impact has a particularly high risk of serious injury at a given impact speed (Doecke *et al.* 2020). Had the sample included more crashes in outer regional and rural areas, the percentage of crashes that would have been mitigated with a centre barrier may have been higher still.

4.2.2. Vehicle technology-based interventions for trucks

ESC for trucks was found to be the vehicle technology that would have prevented the most truck crashes. This was consistent between the whole sample, and only the crashes resulting in hospital admission or fatality. ESC for trucks is primarily aimed at preventing rollover crashes, though it may also have benefits for crash types in which the truck driver loses control of the truck, or understeers to such a degree that a crash occurs. Trailer roll stability for trucks was also found to feature highly in the prevention interventions. Prior research applying effectiveness estimations to mass crash data has estimated that mandating ESC for heavy vehicles in Australia would prevent 4% of fatal heavy vehicle crashes (Budd & Newstead, 2014). In the present study, 12% of the total sample and 10% of the serious injury truck crashes were found by the review panel to be preventable with truck ESC, with a medium to high degree of confidence. While not directly comparable, these findings appear to be somewhat consistent despite employing vastly different methodologies. ESC has now been mandated for new models of trucks in Australia from November 2023 and for all new trucks from February 2025 (Hogan, 2022) and this present study provides some further evidence to support that decision.

Autonomous Emergency Braking (AEB) for trucks was another vehicle technology that featured highly on the list of prevention interventions. However, AEB for trucks was found to prevent a much higher proportion of all the crashes investigated (9%) than of the high severity crashes only (4%). This is an expected result as AEB is primarily effective in rear end crashes which tend to be lower in severity than other crash types. However, this is not consistent with the aforementioned work of Budd and Newstead (2014) that used effectiveness estimates applied to applicable crashes in the mass data. Budd and Newstead found that truck AEB systems could reduce heavy vehicle fatal crashes by 25%. It seems that much of this difference can be explained by the crashes to which AEB was assumed to be applicable in Budd and Newstead (2014), which was based on an early understanding of AEB employed by Anderson (2011), that now appears to be too broad. The results of the present study suggest that AEB for trucks will be effective in reducing crashes involving trucks but not to the degree suggested by former studies. However, if future AEB systems can address more crash types, higher crash reductions may be achieved.

4.2.3. Human behaviour-based interventions

The interventions that would have prevented the most crashes where generally road or vehicle based. The top prevention intervention that was not road or vehicle based was apprehension for a drink/drug driving offence. This is consistent with the prior finding from a sample of crashes not focussed on trucks (Doecke, Thompson & Stokes, 2020). However, in Doecke, Thompson & Stokes (2020), alcohol and drugs were found to be equally common in the proportion of cases in which they were found to be a contributing factor (9%), whereas, in the present study, drugs were a far more common contributing factor than alcohol (4% and 1% respectively) though both were overall less common than in Doecke, Thompson & Stokes (2020). More crashes could be prevented with apprehension for a drug or alcohol offence (9%) than those cases in which drugs or alcohol were considered a contributing factor (5%) because there were a number of cases in which drugs were detected in a driver's system which would have resulted in direction from police not to continue driving but it was not determined by the review panel that the drugs in their system actually contributed to the crash. The intervention of apprehension for drink/drug driving was more likely to apply to the other road user, rather than the truck driver.

4.2.4. Speed related interventions

The findings of this study further reinforce the important role of speed reduction in crash mitigation and prevention. The top two interventions for crash mitigation related to speed reduction, either through a reduction in the speed limit, or vertical deflection at intersections. Speed limit reductions and vertical deflection also ranked highly among the interventions that could have prevented crashes. Furthermore, one of the mechanisms of crash prevention and mitigation of roundabouts, the top prevention intervention, is through speed reduction on the approach to and through intersections (Elvik *et al*., 2009). This is consistent both with the prior study that analysed a sample of in-depth crash investigations that did not focus on trucks (Doecke, Thompson & Stokes*.,* 2020), and much prior research on the influence of speed on crashes (e.g., Kloeden *et al.,* 1997, Elvik *et al.* 2019, Doecke *et al.,* 2020).

4.2.5. General considerations regarding interventions

The results from this study demonstrate that there are several interventions that could have prevented individual crashes or mitigated the injuries in individual crashes. However, the interventions proposed in this study are somewhat aspirational as they have been made with little consideration to practicality, feasibility or cost-effectiveness. In terms of potential effectiveness of the proposed road or infrastructure interventions, treating individual crash locations identified in this study is unlikely to have a considerable system-wide road safety benefit. Treating one individual location as a reactive measure does not consider the effects of regression-to-the-mean and that a similar traffic scenario at a different location may result in the same crash and outcome. Hence a system-wide approach (treating all similar roads with the same intervention) or a system-wide optimised intervention would result in a better road safety outcome. A system-wide optimised approach would prioritise treatment of traffic routes that have higher average traffic volumes of heavy vehicles (and hence higher exposure to crash potential and higher severity of crash) compared to other traffic routes. In addition to these types of treatments, encouraging or designating heavy vehicle users only to use these treated routes whenever possible may also have a road safety benefit.

Vehicle based interventions also need widespread deployment to have a meaningful road safety benefit. This can be achieved through regulation, though the technologies are usually first mandated only on new models before being mandated on all new vehicles. This means that fleet penetration of the mandated technology is limited by the fleet turnover. Consumer rating schemes may also be a mechanism for increasing the adoption of a vehicle safety technology. Such a rating scheme for heavy goods vehicles has recently been developed in Europe (Knight, Grover & Avery, 2023). The developers of this new scheme state that the keys to such a scheme meeting its objectives are that it goes much further than regulation while taking less of a one-size-fits-all approach, not adding more constraints on the industry, and linking to local initiatives regarding access, such as London’s heavy goods vehicle safety permit, or financial incentives (Knight, Grover & Avery, 2023). A similar scheme, adapted to the Australian situation, may prove beneficial.

It should be acknowledged that there were potential biases in the review process that nominated contributing factors and interventions. Firstly, the process was subjective as it relied on the knowledge of the panel of experts and their ability to predict the outcome of a crash had a certain circumstance been different. However, the panel consisted of experts in the three key areas of road safety – human factors, road design and vehicles – and this approach would help to balance bias towards each expert's own area of expertise. Additional expertise in specific areas was also drawn on when required, for example about the influence of a certain drug or medical condition on driving performance. The intention was to derive all opinions from a strong knowledge base. It was also a requirement that the expert proposing an intervention to the panel explain why an intervention would be effective for a crash, which would often lead to some debate before a decision was reached. It was not thought that this process would eliminate the bias completely, but that it was likely that a different panel of experts would have produced similar results. This method would certainly provide substantial benefits over having a single person choosing contributing factors and interventions.

4.3. Limitations

4.3.1. The representativeness of the sample

When interpreting the results, it is important to take into consideration the nature of the sample of crashes that were investigated. The truck-focused study was conducted within a limited geographical area, spanning a radius of 200 km from Adelaide, and during specific hours from 7 am to 9 pm on weekdays and Saturdays, and 9 am to 9 pm on Sundays. Additionally, follow-up investigations were conducted for high-profile, fatal, or potentially fatal cases. Crashes were investigated if they met a minimum criterion of ambulance transportation to a hospital. However, if the crash occurred on a road with a speed limit of 100 km/h or more, or if the crash involved a truck rolling over, it was included in the sample regardless of the injury outcome. Furthermore, earlier truck crashes investigated as part of CASR's on-going in-depth crash investigations were also included in the analysis. These investigations were conducted within a smaller radius (100 km) and are strictly limited by the ambulance transportation criterion.

Due to these sampling method characteristics, the sample did noy represent the following South Australian truck crashes:

- Crashes occurring more than 200 km away from Adelaide.
- Crashes occurring on Kangaroo Island
- Crashes with a severity lower than very serious or fatal (not investigated by MCIS), occurring between the hours of 9 pm and 7 am.

In comparison to all police reported casualty truck crashes during an equivalent period, the collected sample exhibited an overrepresentation of cases with the following characteristics:

- Cases involving a fatality
- Non-injury and minor injury cases
- Crashes occurring in an 80 km/h speed zone
- Right angle crashes
- Rollover crashes
- U-turn in front crashes

There was also an underrepresentation of crashes with the following characteristics:

- Crashes occurring in a 60 km/h speed zone
- Side swipe crashes

- Rear-end crashes

These differences and discrepancies between the collected sample and the broader TARS sample should be considered when interpreting the results and attempting to draw conclusions about truck-involved crashes across South Australia. It is important to recognise that the findings may not directly represent the entire spectrum of truck crashes in South Australia. The exact effect of the biases in the sample on the results, in terms of contributing factors and interventions, is not able to be determined as the very purpose of the investigations was to collect data not already available. However, some potential effects can be surmised. It seems likely that fatigue, alcohol and drug affected driving, and non-restraint use may be under-represented in the sample. Factors and associated interventions particular to long distance trucking may also be under-represented. The over and under-representation of different crash types also means that the contributing factors and interventions associated with these particular types of crashes may be biased in a similar manner.

To generalise the results to other Australian states or the whole of Australia, differences between the area in which the crashes were investigated and the area in question should be considered. One notable difference between SA and the more populous eastern states is the extent of the motorway network within the major city area. Traffic volumes within the major cities would also be less in South Australia than the eastern states. How the inner regional and outer regional areas in which the crashes were collected compared to the rest of Australia is less clear. SA appears to have a greater proportion of its rural road network with a speed limit of 110 km/h than some other states. This is evidenced by fatal crash statistics. The speed zone with the highest number of fatalities in South Australia is 110 km/h zones, similar to Western Australia, but in contrast to the eastern states where fewer fatalities occur in 110 km/h zones than in 50 km/h zones (Office of Road Safety, 2023). There may also be additional differences between SA and the rest of Australia, including: the layout of the road network, the road design, the topography, and the prevalence of different truck configurations. In general, it is thought that the sample would be reasonably representative of crashes within the major cities and inner regional areas of Australia, though the addition of crashes collected from one of the eastern states would likely improve how nationally representative the data is.

4.3.2. The COVID-19 Pandemic

The potential effects of the of the COVID-19 pandemic on the sample must also be considered. According to research produced by Elsegood *et al*. (2022), throughout the year of 2020 (when societal changes due to the pandemic were most notable), traffic volumes of all vehicles in South Australia decreased by 8.5% compared to the previous two years. The findings of Elsegood *et al.* (2022), however, did not distinguish between heavy vehicles and passenger vehicles. There were also interstate travel restrictions that may have affected the travel patterns of heavy vehicles. These factors may have resulted in a higher proportion of the vehicles on the road being trucks, though how this may have affected the results is unclear.

4.3.3. Missing information

It is also important to consider that, as detailed in the results, not all information could be collected for each case. The impact that this had on the results depends on the type of information that was lacking. A lack of detailed injury data in about a third of cases limited the case review panel’s ability to select mitigating interventions with a high degree of confidence. While this is tempered somewhat by these crashes tending to be lower severity crashes, it may have still resulted in the impact of mitigating interventions being underestimated. This may also have impacted the identification of medical conditions, alcohol, and drugs as contributing factors.

The inability of investigators to carry out detailed mechanical inspections of trucks in many instances means that mechanical faults are likely to be under-represented in the contributing factors identified. Furthermore, the total weight of loaded trucks was usually only self-reported, with objective data only available for a small number of cases, potentially leading to an under-representation of the identification of overloaded trucks.

Interviews with the drivers often play an important role in identifying human factors that contributed to a crash. As only 40% of drivers could be interviewed, contributing factors that are particularly difficult to confidently identify without an interview, such as distraction, fatigue, and factors associated with failing to give way, may be under-represented. That sufficient evidence to determine travel and impact speeds was not available in all cases may mean that exceeding the speed limit may also be under-represented in the contributing factors identified.

The under-representation of certain contributing factors due to a lack of pertinent data is also likely to have led to an under-representation of certain interventions. For example, if exceeding the speed limit was under-represented, interventions that have the potential to prevent or discourage this from occurring, like Intelligent Speed Adaptation, would also be under-represented. All of these factors should also be considered when interpreting the results, and future studies should consider how these limitations can be overcome.

4.3.4. Lack of data on truck specifications

A final limitation that was identified when undertaking this study was the lack of a public database on truck specifications. The investigators attempted to identify what vehicle safety technologies trucks were equipped with, but it is possible that some were present but could not be readily visually identified. For light vehicles, the problem of at-scene visual identification is overcome with the availability of detailed vehicle specifications based on make, model and year, or vehicle identification number (VIN). No such database exists for trucks sold in Australia. This limitation may have resulted in an over estimation of the impact of vehicle technology-based interventions if investigators were unable to identify that a vehicle was equipped with a technology that, in the case review panel's opinion, could have prevented or mitigated the crash.

5. Conclusions

Human factors were found to have contributed to the most truck crashes, consistent with prior studies that did not focus on trucks. However, vehicle factors were found to have contributed to a greater proportion of the truck crashes than a prior study not focussed on trucks conducted within a similar geographic area with a similar methodology. This is despite the acknowledged difficulties with mechanical inspection of trucks. The most frequent vehicle related contributing factor was the dynamic stability of the truck, followed by truck blind spots.

Speed, both ‘too high for conditions’ and ‘exceeding the limit’, was found to be a common contributing factor. Trucks exceeding the speed limit is of particular concern given their aggressivity.

Human errors associated with failing to give way at an intersection were also found to be common contributing factors for both truck drivers and the other road user. A difference was found between the two road users in the nature of these human errors. Truck drivers were more likely to fail to adequately check for traffic, while the other road users were more likely to fail to check for traffic at all. Failure to obey a traffic signal also contributed to a number of intersection crashes, with the failure occurring in similar numbers for both trucks and the other road user.

While human factors contributed to the most truck crashes, road and vehicle-based interventions were found to have the greatest potential to prevent and mitigate truck crashes. Road-based interventions aimed at preventing and mitigating crashes at intersections were found to be particularly important for truck crashes. These interventions included roundabouts, the installation of traffic lights (with fully controlled right turns), grade separating junctions, preventing right turns, vertical deflection, and improving the geometry of the junction. These interventions will not only prevent and mitigate truck crashes but have also been previously found to be the top interventions for all crashes.

The truck technologies found to have the most potential for crash prevention and mitigation were ESC (and the associated Trailer Roll Stability Systems) and AEB. This further reinforces the recent decision to mandate these technologies on new trucks. Lane Keep Assist for the light vehicle would also have prevented a number of the truck crashes.

Speed reduction was found to be important for mitigation of truck crashes. Reducing the speed limit by up to 20 km/h was the intervention that had highest crash mitigation potential, especially for serious injury crashes. Other interventions that reduce speeds, particularly through intersections, were also found to have strong potential for crash mitigation.

Centre barriers were also found to be important for truck crash mitigation. In many instances a centre barrier only designed for light vehicles was judged to be sufficient to mitigate the crash, though there were some instances where centre barriers capable of retaining a truck would likely have been required.

The maximum benefit can be achieved from the aforementioned interventions if a system-wide approach is taken. For road-based interventions this means proactive widespread application of interventions rather than reactive installation at individual locations. For vehicle technologies this means encouraging rapid take-up through a combination of regulation, incentives, and consumer rating schemes.

6. Future work

As this study has produced the first substantial dataset of in-depth no-blame truck crash investigations in Australia there is much scope for future work to be carried out with this dataset, and through extending this dataset.

Specific topics for future research could include, but are not limited to:

- truck rollovers
- intersection crashes involving trucks
- truck blind spots and their contributory role in crashes
- the width of roads and truck access
- methods to reduce speeding by truck drivers
- traffic offence history of truck drivers and crash involvement
- compatibility issues in truck crashes
- the nature of injuries in truck crashes
- head on crashes involving trucks

Acknowledgements

This research was funded by the Australian Government and administered by the Office of Road Safety, Road Safety Innovation Fund.

The authors would like to acknowledge the assistance of many members of South Australia Police, and in particular Eliot McDonald, Senior Sergeant David Kuchenmeister, Christine Basso, Sergeant Mark Fulcher, Detective Senior Sergeant David Gordge, Senior Sergeant Stephen Murray and Senior Sergeant Mick Ellis.

The authors would also like to acknowledge the assistance of many members of the Metropolitan Fire Service, Country Fire Service, and South Australian Ambulance Services.

Thanks also to Jeff Potter (National Transport Council), Bill McKinley (Australian Trucking Association) and Greg Fill (National Heavy Vehicle Regulator) for their advice.

The authors are also grateful to the many tow truck companies, tow truck drivers and crash repairers who assisted the investigations.

The authors would also like to acknowledge Matthew Baldock’s assistance with the proofreading of this report.

Finally, the authors would like to thank the road users and witnesses who consented to, and made the time for, an interview regarding a crash.

The views expressed in this report are those of the authors and do not necessarily represent those of the University of Adelaide or the funding organisations.

References

ABS (2016) Australian Statistical Geography Standard (ASGS): Volume 5 - Remoteness Structure. Canberra: Australian Bureau of Statistics

Anderson, R. W. G., Hutchinson, T. P., Linke, B. J., & Ponte, G. (2011). Analysis of crash data to estimate the benefits of emerging vehicle technology (CASR094). Adelaide: Centre for Automotive Safety Research.

Association for the Advancement of Automotive Medicine. (2018*). Abbreviated Injury Scale: 2015 Revision* (6 ed.). Chicago, IL.

Bahouth, G., Digges, K., & Schulman, C. (2012). Influence of injury risk thresholds on the performance of an algorithm to predict crashes with serious injuries. In *Annals of Advances in Automotive Medicine/Annual Scientific Conference* (Vol. 56, p. 223). Association for the Advancement of Automotive Medicine.

Bahouth, G., Graygo, J., Digges, K., Schulman, C., & Baur, P. (2014). The benefits and tradeoffs for varied high-severity injury risk thresholds for advanced automatic crash notification systems. *Traffic injury prevention*, 15(sup1), S134-S140.

Brumbelow, M. L. (2019). Front crash injury risks for restrained drivers in good-rated vehicles by age, impact configuration, and EDR-based delta V. In *Proceedings of IRCOBI Conference*.

Bureau of Infrastructure, Transport and Regional Economics (BITRE) 2019. *Australian aggregate freight forecasts – 2019 update* (Research Report 152). Canberra: BITRE.

Bureau of Infrastructure, Transport and Regional Economics (BITRE) 2023. *Road trauma involving heavy vehicles 2021 crash statistical summary*. Canberra: BITRE.

Budd, L., Newstead, S. (2014) *Potential safety benefits of emerging crash avoidance technologies in Australasian Heavy Vehicles* (Report No. 324) Clayton: Monash University Accident Research Centre.

Budd, L., Newstead, S., Watson, L. (2021*). An analysis of heavy vehicle safety performance in Australia.* Clayton: Monash University Accident Research Centre.

Doecke, S. D., Baldock, M. R. J., Kloeden, C. N., & Dutschke, J. K. (2020). Impact speed and the risk of serious injury in vehicle crashes. *Accident Analysis and Prevention, 144*, September 2020, 105629.

Doecke, S. D., Thompson, J. P., & Stokes, C. S. (2020). How do we prevent and mitigate crashes? Evidence from Australian at-scene in-depth crash investigations. *Journal of Road Safety, 31*(2), 35-43.

Elvik, R., Høye, A., Vaa, T., & Sørensen, M. (2009). The Handbook of Road Safety Measures. Bingley, United Kingdom: Emerald Group Publishing Limited.

Elsegood, M. E., Kloeden, C. N., & Mackenzie, J. R. R. (2022). *Traffic and road safety effects of the 2020 COVID-19 restrictions in South Australia* (CASR187). Adelaide: Centre for Automotive Safety Research.

Federal Motor Carrier Safety Administration (2007). *The Large Truck Crash Causation Study – Analysis Brief.* https://www.fmcsa.dot.gov/safety/research-and-analysis/large-truck-crash-causation-study-analysis-brief

Fitzharris, M., Lenné, M. G., Corben, B., Pok Arundell, T., Peiris, S., Liu, S., Stephens, A. Fitzgerald, M., Judson, R., Bowman, D., Gabler, C., Morris, A., Tingvall, C. *ECIS Report 1: Overview and analysis of crash types, injury outcomes and contributing factors.* (Report No. 343) Clayton: Monash University Accident Research Centre.

Gibson, A (2022) *NTARC Major Crash Investigation 2022 Report.* National Truck Accident Research Centre.

Hanson (2020) *Blind Spot Diagrams* Retrieved March 17, 2023, from https://www.nrspp.org.au/resources/blind-spot-diagrams/.

Hogan, K. (2022) *Saving lives with new technologies in heavy vehicles* [press release] https://parlinfo.aph.gov.au/parlInfo/search/display/display.w3p;query=Id%3A%22media%2Fpressrel%2F8455910%22;src1=sm1

Kloeden, C. N., McLean, A. J., Moore, V. M., & Ponte, G. (1997). *Travelling speed and the risk of crash involvement. Volumes 1 and 2* (CR172). Canberra: Federal Office of Road Safety, Transport and Communications.

Knight, I., Grover, C., Avery, M. (2023) Developing a consumer safety rating for heavy goods vehicles *in 27th International Technical Conference on the Enhanced Safety of Vehicles (ESV): National Highway Traffic Safety Administration (No. 23-0264).*

McLean, A. J. (1973). *A review of in-depth studies in relation to road safety* (NR/22). Canberra: Australian Government Publishing Service.

McLean, A. J. (2005). *Fifty years of at-scene crash investigations: methodological considerations.* 2005 Australasian Road Safety Research, Policing, Education Conference, Wellington, New Zealand, 14-16 November 2005.

Office of Road Safety (2023) *Road deaths dashboard* accessed 25 July 2023 https://www.officeofroadsafety.gov.au/data-hub/fatalities-data

Segal, M. D. (1970). The" in-depth" approach to collision investigation. *Traffic Safety, 70*(8).

Stokes, C. S., & Woolley, J. E. (2022). *A comparison of uncontrolled, give way sign controlled and stop sign controlled intersections in South Australia* (CASR151). Adelaide: Centre for Automotive Safety Research.

Sutphen, R. F., & Varner, R. W. (2003). Commercial Vehicle Accident Reconstruction and Investigation. Tucson: Lawyers & Judges Publishing.

Thompson, J. P., & Wundersitz, L. N. (in press). *The contribution of driver fatigue to casualty and fatal crashes in South Australia* (CASR197). Adelaide: Centre for Automotive Safety Research.

Transport for NSW (2020) *Safety features and technologies for heavy vehicles.* Sydney: Transport for NSW

Appendix A
Contributing factors and interventions

Table A.1 (Part 1)
List of all contributing factors

Contributing factors
Human: exceed speed limit
Human: speed too high for conditions
Human: alcohol
Human: drugs
Human: inexperience
Human: young driver
Human: vision
Human: medical condition
Human: suicide
Human: unfamiliarity with vehicle
Human: unfamiliarity with road
Human: unsafe overtaking
Human: deliberate unsafe act
Human: misjudgement
Human: fail to give way unspecified
Human: disobey traffic signal
Human: fatigue
Human: fail to check for traffic
Human: fail to adequately check for traffic
Human: recognition failure
Human: distraction
Human: inattention
Human: competing demands for attention
Human: attention unspecified
Human: tailgating
Human: avoid other errant vehicle
Human: incorrect positioning
Human: impulsive decision
Human: peer effects
Human: pedestrian conspicuity
Human: other
Human: unknown
Road: wet road
Road: obstacle on road
Road: large roadside drop off
Road: unsealed road
Road: horizontal alignment
Road: vertical alignment
Road: superelevation
Road: delineation
Road: road marking

Table A.1 (Part 2)
List of all contributing factors

Contributing factors
Road: road layout
Road: visibility
Road: road surface
Road: signage
Road: signal control
Road: unsealed shoulder
Road: unexpected road or traffic conditions
Road: roadworks
Road: weather conditions
Road: road width
Vehicle: brakes
Vehicle: conspicuity
Vehicle: steering
Vehicle: dirty
Vehicle: tinted windows
Vehicle: dynamic stability
Vehicle: tyre low tread depth
Vehicle: tyre blowout
Vehicle: overload
Vehicle: modified vehicle
Vehicle: blind spot
Vehicle: new motorcycle tyres
Vehicle: other

Table A.2 (Part 1)
List of all interventions

Interventions
Addition of drug to drug driver testing
Apprehension for speed offence
Apprehension for drink/drug driving offence
Apprehension for young driver restriction offence
Apprehension for L-driver restriction offence
Apprehension for overloading of vehicle
Apprehension for unlicensed driver
Brighter clothing worn
Instant loss of licence for breach of licence conditions
Suspension of licence for being medically unfit to drive
Better medical control of/advice regarding medication
Driver training/re-training
Geographical restriction on licence
Mental health treatment
Medical treatment
Motorcycle Airbag Jacket
Navigation by GPS
Requirement for motorcycle license to ride scooter
Route planning

Table A.2 (Part 2)
List of all interventions

Interventions
Safe transportation planning for drunk person
Smoking banned while driving
Treatment for alcohol and drug dependence
Trip planning
Wearing of better protective clothing
Wearing of helmet
Wearing of seatbelt
Workplace fatigue management
ABS
Active head rest
Adaptive Cruise Control
AEB
AEB reversing
Alcohol interlock for all prior drink driving offenders
Alcohol interlock in all vehicles
Anti-theft device
Auto high beam dimming
Automatic Crash Notification
Blindspot warning
Brake emergency display
Collision Warning
Combined braking system
Curtain airbag
Curve Speed Warning
Daytime running lights
Door interlock
Drivers airbag
Drowsiness Detection / Warning
Emergency Braking Assist
ESC
Flashing lights activated on bicycle
ISA - Advisory
ISA - Limiting
Keyless ignition
Knee airbag
Lane Departure Warning
Lane Keep Assist
Mobile phone blocking technology
Park brake not activated warning
Passenger airbag
Rear seat seatbelt pretensioners + load limiters
Seatbelt interlock
Seatbelt load limiters
Seatbelt pretensioners
Side airbag
Sign recognition

Table A.2 (Part 3)
List of all interventions

Interventions
Top Speed Limiter
Traction Control
Unlicensed driver interlock
Booster seat
Correct installation of child seat
Forward facing child restraint
Rear facing child restraint
Adding a bull bar
Correct tyre pressures
Correctly maintained brake system
Fixing of engine defect
Frontal impact intrusion protection
Improved bicycle helmet design
Lower centre of gravity
More tread depth on tyres
More Visible colour
New motorcycle tyres that don't need to be run-in
Pedestrian protection
Puncture resistant / run flat tyres
Reduced vehicle aggressivity
Removing bull bar
Rollover structural integrity
Side intrusion protection
Window tinting removal
Animal underpass/overpass + roadside fencing
Bike lane
Bus bay
Bus lane
Clearance between parking and bike lane
Controlled right turn (signalised intersection)
Curve re-profiling
Dedicated parking bay
Early amber traffic light for cyclists
Frangible pole
Grade separated junction
Improved channelisation
Improved geometry of junction
Improved mobile network coverage
Improved sight distance
Kerb extension
Left in left out junction
Left turn lane
Median holding space
Narrow centre median (1m)
Offset non-priority road
One way road

Table A.2 (Part 4)
List of all interventions

Interventions
Overtaking lane
Pedestrian priority crossing (unsignalised)
Pedestrian signals
Pedestrian/cyclist over/underpass
Prevent right turn
Prevent roadside parking
Removal of slip lane
Rest area
Right turn lane
Roundabout
Safety camera at signalised junction
Safe U-turn provision
Separated bicycle lane
Separated road
Shared space
Single lane of traffic
Speed limit reduction
Speed reduction by design (e.g. LATM)
Vertical deflection
Wide centre median (5m+)
Wider footpath
Audio tactile centre lines
Audio tactile edge line
Centre barrier
Centre line
Clear zone to guidelines
Edge of road line
Improved barrier end treatment
Improved line marking
Improved road drainage
Improved road surface (remove undulations and defects)
Improved superelevation
Improved surface friction
Motorcycle protection on barrier
Raised median
Reflective pavement markers
Roadside tree pruning
Road surface cleaning
Sealed road
Sealed shoulders
Side barrier
Solid centre line (overtaking prohibited)
Widen road
Active curve advisory speed alert sign
Active warning sign for slow moving vehicle on descent
Centre give way sign

Table A.2 (Part 5)
List of all interventions

Interventions
Chevrons
Curve speed advisory sign
Give way sign
Guide posts
Hazard ahead warning sign
Improved route signage
Improved sign visibility
Longer amber duration at signalised intersection
Lower curve speed advisory sign
No U-turn sign
Overhead flashing intersection warning sign
Pedestrian fencing
Pedestrian priority in sequence at signalised junction
Retro reflective signs
Rural Junction Active Warning Sign (RJAWS)
Stop sign
Stop sign in the centre of the road
Street lighting
Traffic lights
Variable speed limit sign
Warning signs
Drivers airbag + seatbelt pretensioners
Frontal impact intrusion protection + drivers airbag + seatbelt pretensioners
Lane Departure Warning + sealed shoulders
Narrow centre median (1m) + audio tactile centre lines
Pedestrian fencing + wider footpath
Sealed shoulders + audio tactile edge lines
Sealed shoulders + audio tactile centre line
Sealed shoulders + Lane Departure Warning
Sealed road + audio tactile centre line
Sealed road + lane marking + lane keep assist
Sealed road + rumble strips
Seatbelt load limiters + pretensioners + drivers airbag
Seatbelt load limiters + pretensioners
Side intrusion protection + Side airbag + Curtain airbag
TRUCK Electronic Stability Control (ESC) System
TRUCK Trailer Roll Stability (TRS) System
TRUCK Autonomous Emergency Braking (AEB) System
TRUCK Electronic Braking System (EBS)
TRUCK Electronic Brake Distribution (EBD) System
TRUCK Load-Proportioning Brake Valve (LPBV) System
TRUCK Adaptive Cruise Control (ACC) System
TRUCK Driver Fatigue Monitoring System
TRUCK Wheel Nut Indicators and Locks
TRUCK Antilock Braking Systems (ABS)
TRUCK Antilock Braking Systems (ABS) trailer

Table A.2 (Part 6)
List of all interventions

Interventions
TRUCK Disc Brakes
TRUCK Lane Departure Warning System (LDWS)
TRUCK Daytime Running Lamps (DRL)
TRUCK Blind Spot Elimination System
TRUCK Enhanced Night Vision (ENV) System
TRUCK Emergency Stop Light
TRUCK Enhanced Vehicle Visibility Markings
TRUCK Tyre Puncture Prevention
TRUCK Reversing Safety Systems
TRUCK Alcohol Ignition Interlocks
TRUCK Frontal under-run protection
TRUCK Side under-run protection
TRUCK Rear under-run protection
TRUCK Drivers airbag
TRUCK Curtain airbag
TRUCK Passenger airbag
TRUCK Increased cabin strength
TRUCK Seatbelt reminder
TRUCK Automatic Brake Adjustment (ABA) Devices
TRUCK Intelligent Speed Adaptation (ISA) Warning System
TRUCK Fire Suppression Systems
TRUCK Automatic Crash Notification (ACN) System
TRUCK Emergency Hatch
TRUCK Uneven load warning system
TRUCK truck specific roadside barrier
TRUCK mirrors that do not create a blindspot
TRUCK Truck lane on ascent/descent
TRUCK arrester bed at bottom of descent
TRUCK descent warning sign
TRUCK high performance brakes
TRUCK lane keep assist
TRUCK automatic suspension adjustment for unladen truck
TRUCK more tread depth on tyres
TRUCK Curve Speed Warning
TRUCK seatbelt pretensioners
TRUCK seatbelt load limiters
TRUCK bypass route
TRUCK Removing bull bar
TRUCK Collision Warning
TRUCK Removal of load overhang