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TITLE

The contribution of driver fatigue to casualty and fatal crashes in South Australia

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ABSTRACT

Determining whether fatigue (referring to a person falling asleep or experiencing deficits in functioning due to being tired, drowsy, or sleepy) is involved in a motor vehicle crash is difficult. Consequently, there is high variability in estimates of the contribution of fatigue to crashes. This study explored the contribution of driver fatigue to casualty and fatal crashes in South Australia, as well as the role that fatigue played in the crashes, the risk factors that led to the fatigue and the countermeasures that could have prevented the crashes. Data from two sources were examined: in-depth at-the-scene investigations of casualty crashes by the Centre for Automotive Safety Research (2014 to 2019) and Coroner reports on fatal crashes (2014 to 2015). Fatigue-related crashes were identified through evaluation of various forms of evidence (e.g., from crash participant/witness interviews, events preceding the crash). Fatigue contributed to 4.3% of casualty crashes and 11.5% of fatal crashes. Most fatigue crashes occurred during daylight hours (72.4%), on high-speed roads (86.2%), and at midblock locations (89.7%), and most (82.8%) involved the driver falling asleep, leading to the vehicle departing its lane, and either rolling over or colliding with a roadside object or oncoming vehicles. The most common risk factors for fatigue were long distance driving (41.4% of crashes), no/reduced/broken sleep (27.6% of crashes), illicit drug use (17.2% of crashes), and abnormal work/sleep routines (17.2% of crashes). The countermeasures that could have prevented the most fatigue crashes were lane keep assist (could have prevented 79.3% of crashes), lane departure warnings (65.6%), drowsiness detection/warnings (55.2%), audio tactile centre lines (41.4%), and autonomous emergency braking (34.5%). Vehicle technologies, therefore, comprised four of the five most common countermeasures. This study was the first, of which the authors are aware, to estimate the contribution of driver fatigue to crashes within South Australia.

KEYWORDS

Fatigue, sleepiness, crashes, risk factors, countermeasures

Summary

Determining whether fatigue (referring to a person falling asleep or experiencing deficits in functioning due to being tired, drowsy, or sleepy) is involved in a motor vehicle crash is difficult. Consequently, there is limited literature estimating the contribution of fatigue to crashes and high variability in the estimates. Additionally, the role that fatigue plays (e.g., driver fell asleep, diminished attention) in crashes and the risk factors that lead to fatigue (e.g., working long hours) need to be examined and better understood to prevent these crashes. This study explored the contribution of driver fatigue to casualty and fatal crashes in South Australia, as well as the role that fatigue played in the crashes, the risk factors that led to the fatigue and the countermeasures that could have prevented the crashes from occurring.

Detailed crash investigation data from two sources were examined: in-depth at-the-scene investigations of casualty crashes in South Australia by the Centre for Automotive Safety Research (CASR) (2014 to 2019) and reports on fatal crashes (2014 to 2015) prepared by the South Australian Coroner. Fatigue-related crashes were identified through a detailed review of the evidence from each crash (e.g., from crash participant/witness interviews, background information, details of preceding events). The proportions of casualty and fatal crashes that involved fatigue were determined. Characteristics of fatigue crashes (e.g., time of day, speed limit, metropolitan or rural) were also examined in comparison to non-fatigue crashes within the same datasets. Finally, the role of fatigue in the crash (e.g., crash type, lane departures, attempted corrective steering) was examined, along with risk factors that led to fatigue (e.g., working night shift).

The results revealed that fatigue contributed to 11 (4.3%) of 254 casualty crashes and 18 (11.5%) of 156 fatal crashes in South Australia. These estimates should be considered conservative due to the stringent criteria that there was clear evidence of fatigue contributing to the crash (and limitations in the hours and coverage of the in-depth crash investigations for casualty crashes).

Most fatigue crashes occurred during daylight hours (72.4%), on high-speed roads (86.2%), at midblock locations (89.7%), and involved the driver falling asleep, causing the vehicle to depart its lane, and either rolling over or colliding with a roadside object or oncoming vehicles (82.8%). Casualty fatigue crashes were more likely to involve a single vehicle compared to non-fatigue casualty crashes (70.0% versus 32.2%). Fatal fatigue crashes were more likely to occur on rural roads than non-fatigue fatal crashes (100% versus 66.7%). The most common risk factors for fatigue were long distance driving (41.4% of crashes), no/reduced/broken sleep (27.6% of crashes), illicit drug use (17.2% of crashes), and abnormal work/sleep routines (17.2% of crashes). The countermeasures that could have prevented the most fatigue crashes were:

- Lane keep assist – could have prevented 79.3% of crashes.
- Lane departure warning – 65.6%.
- Drowsiness detection/warning – 55.2%.
- Audio tactile centre lines – 41.4%.
- Autonomous emergency braking – 34.5%.

This study was the first, of which the authors are aware, to estimate the contribution of driver fatigue to crashes within South Australia. It builds on previous limited research into fatigue crashes by providing a broad understanding of the mechanisms through which fatigue contributes to crashes and the risk factors for driving while fatigued. The findings will assist in the targeting of future public education messaging to prevent driving while fatigued and have identified that vehicle technologies are likely to be the most effective countermeasures for preventing fatigue crashes.

Contents

1 Introduction

Determining whether fatigue (referring to a person falling asleep or experiencing deficits in functioning due to being tired, drowsy, or sleepy) was involved in a motor vehicle crash is difficult (Connor, Whitlock, Norton, & Jackson, 2001; Dawson, Reynolds, Van Dongen, & Thomas, 2018; Filtness, Armstrong, Watson, & Smith, 2017). Fatigue (or drowsiness/sleepiness) is an internal psychological state that is difficult to define and cannot be objectively measured (Dawson et al., 2018; Palamara, 2016). The positive identification of fatigue in a crash-involved driver requires clear evidence, which is often not available.

As a result, there is high variability in estimates of the extent to which fatigue contributes to crashes (Dawson et al., 2018), particularly when compared to other causes of crashes (e.g., speeding, drink driving). The Australian Transport Council (2011) estimated fatigue may be a contributing factor in 20 to 30% of Australian casualty crashes. A report by the New South Wales Centre for Road Safety (2015) found that fatigue was involved in approximately 10% of non-injury crashes, 8.7% of non-fatal injury crashes, and 16.5% of fatal crashes in New South Wales in 2014. A similar estimate for the contribution of fatigue to fatalities (17.5%) was found by Palamara (2016) in Western Australia between 2009 and 2013. However, a lower estimate (fatigue contributing to approximately 10% of road users killed) was reported in Western Australia in 2017 (Road Safety Commission, 2018). Older research by Dobbie (2002) found that 16.6% of all fatal crashes across Australia in 1998 had sleep-related causes. In New Zealand, fatigue was found to be involved in approximately 12% of fatal crashes between 2014 and 2016 (Ministry of Transport, 2017). Radun and Summala (2004) found that fatigue contributed to 10 to 15% of fatal road crashes in Finland between 1991 and 2001.

Road authorities, when attempting to measure the extent of fatigue-related crashes, tend to rely on ‘operational definitions’ of a fatigue-related crash based on the crash having certain characteristics. Mass crash databases are then searched for crashes that match these characteristics to provide an estimate of how many crashes involve fatigue (Dawson et al., 2018). These operational definitions that are used as proxies for fatigue crashes (Filtness et al., 2017) are often based on simple information about the crash (e.g., type/time of crash). For example, in South Australia, the following operational definition, developed by the Australian Transport Safety Bureau, is used:

- Single vehicle crashes that occur during critical times (midnight to 6am and 2pm to 4pm).
- Head-on collisions in which neither vehicle is overtaking at the time.
- Excludes crashes that: occurred on roads with speed limits under 80 km/h; involved pedestrians; involved unlicensed drivers; involved drivers with high levels of alcohol (BAC over 0.05g/ml).

Operational definitions can result in inaccurate estimates of the problem and are generally considered insufficient (Armstrong, Filtness, Watling, Barraclough, & Haworth, 2013; Crummy, Cameron, Swann, Kossmann, & Naughton, 2008). They make generalised assumptions about the nature of fatigue-related crashes that ignore variability (e.g., they cannot occur outside of critical times or on roads with speed limits of 50 and 60 km/h). Another problem is that the broad definitions may lead to non-fatigue crashes being included in estimates (Cercarelli & Haworth, 2002). There is no universally accepted definition of fatigue, so definitions lack consistency between jurisdictions and research studies are often contradictory when describing the attributes of a fatigue-related crash (Dawson et al., 2018; Horne & Reyner, 1995b; Horne & Reyner, 1999; Smolensky, Di Milia, Ohayon, & Philip, 2011), which could result in differences in estimates. To the best of the knowledge of the authors, there are no studies that have attempted to investigate the contribution of fatigue to South Australian crashes.

An alternative approach is to explore the incidence of fatigue in databases that contain detailed crash investigations (by dedicated police crash investigation units or researchers). Crash investigations of this nature provide crash participant and/or witness interviews, background information about crash participants (e.g., medical history, employment) and details of events leading up to the crash (e.g., sleep routines, working hours, time spent driving). Such information provides positive identification of fatigue-related crashes, rather than using surrogate or proxy measures.

The role fatigue plays in individual crashes is also important to examine. Armstrong, Smith, Steinhardt and Haworth (2008) suggest fatigue crashes in Queensland most often occur in rural, high-speed driving environments with a single vehicle leaving the roadway or crossing the centre line. Similarly, the risk factors that lead to fatigue being a causative factor in crashes are important to understand. Stutts, Wilkins, Osberg and Vaughn (2003) found that drivers in sleep-related crashes were more likely to work multiple jobs, night shifts, and unusual work schedules. They were also more likely to have fewer hours of sleep and poorer sleep quality. Studies have also shown that drivers with medical conditions that cause fatigue, such as sleep apnoea, have an increased risk of crash involvement (Ellen, Marshall, Palayew, Molnar, Wilson, & Man-Song-Hing, 2006; Mulgrew et al., 2008; Tregear, Reston, Schoelles, & Phillips, 2009; Ward et al., 2013). Enhanced understanding of the current role of fatigue in crashes, and the risk factors leading to driver fatigue, is important to prevent fatigue-related crashes from occurring. Detailed crash investigations are able to provide information on these factors.

The purpose of this report was to explore the contribution of driver fatigue to casualty and fatal crashes in South Australia (SA). Data from two sources in SA were examined: in-depth at-the-scene investigations of casualty crashes by the Centre for Automotive Safety Research (CASR) between 2014 and 2019 and reports on fatal crashes between 2014 and 2015 prepared for the state Coroner. Following identification of crashes involving driver fatigue, the crashes were examined to identify the role that fatigue played and the risk factors that led to the fatigue. The countermeasures that could have prevented these crashes were also examined.

The information contained in this report was current as of May 2022.

2 Method

2.1 In-depth casualty crash investigations by the Centre for Automotive Safety Research (CASR)

One of the central research activities at CASR is in-depth, at-the-scene crash investigation. The purposes are to accumulate a highly detailed and accurate database of injury crashes, so that the factors contributing to serious road crashes and injuries can be determined, and potential solutions identified.

2.1.1 Attending a scene and investigating a crash

A crash investigation begins when the team (including researchers from engineering, psychology, and health backgrounds) gets notified by the SA Ambulance Service that an ambulance has been dispatched to a road crash. Two members of the team immediately drive to the crash. They attend a metropolitan crash if it occurs in the city of Adelaide or the surrounding suburbs, within a 30-minute drive from the Adelaide CBD. They attend a rural crash if it occurs within a 100-kilometre radius (approximately 1.5-hour drive) from the CBD. Travel distance/time limitations were established so that evidence at the scene would be preserved when the team arrives. The metropolitan time limitation (30 minutes) is shorter than rural time limitation (1.5-hours) as investigators found that evidence at the scene of metropolitan crashes is cleared more quickly (tow trucks have shorter distances to travel, police clear the scene quickly to get busy intersections and traffic flowing again). A rural crash will also not be attended if it occurs within a rural township, as road conditions and speed limits in townships are like city and suburban areas, which are captured in metropolitan investigations. Crashes in rural townships are also cleared quickly, meaning that investigators will often not reach the scene in time. Other criteria for case selection include:

- at least one participant must be transported to hospital by ambulance (this provides a criterion of crash severity for investigation),
- the crash must occur on a public road (excludes areas such as driveways and carparks), and
- it must include at least one motor vehicle (including motorcycles but excluding single pedestrians and single bicyclists).

During the period in which the crashes included in the present study were investigated, the team was on call to immediately attend crashes during two shifts – 9 am to 2 pm and 2 pm to 9 pm – Monday to Friday. In addition, fatal and life-threatening crashes occurring outside of shift times, which were attended by the Major Crash Investigation Unit of the South Australian Police, were investigated in the following days, as the evidence is preserved by Major Crash (vehicles held, photos of scene taken, scene marked). This means, though, that crashes included in the database that occurred outside of shift times have a bias towards high severity. In total, CASR aims to investigate fifty separate crashes per year.

The following tasks are performed when investigators arrive at the crash:

- talk to emergency services personnel, participants and witnesses to find out what occurred;
- mark the scene evidence (e.g., tyre marks on the road, final positions of vehicles/riders/ pedestrians);
- photograph the scene, vehicles and road infrastructure;
- collect data on the vehicles, road and crash circumstances;
- digitally map the road environment and crash evidence; and

- record videos from the direction of travel of each road user actively involved (physical contact) in the crash.

Further information is obtained after investigators have attended the scene, including:

- the police report,
- the Coroner's report (if fatal),
- the forensics report (alcohol and drug test results),
- the crash history of the location of the crash,
- detailed information on the vehicles involved from online car databases (e.g., size, engine power, safety ratings/technology/features),
- detailed participant injury information (linked to hospital and ambulance records),
- the crash and offence history of drivers involved (linked to their driver licence number), and
- vehicle speeds are determined, if possible, by a computer reconstruction of the crash that utilises the scene evidence and through pre-crash information downloaded from crashed vehicles that contain Event Data Recorders (EDRs).

2.1.2 Participant/witness interviews

Interviews are conducted with participants (drivers, riders, pedestrians) and/or witnesses a month or more after the crash. Interviews provide background information on the individuals and vehicles involved, supplement the data collected at the scene, and help investigators build a complete picture of what happened both in the crash and leading up to it. Interviews are undertaken over the phone or in-person (e.g., CASR office, participant's home). Interviews last around 30 to 40 minutes, during which the following information is requested:

- Personal details of participant.
- Demographics.
- Driving history.
- Details of vehicle involved in crash.
- Drug use and health.
- Crash details.
- Injuries from the crash.
- Other people in vehicle at time of crash.

2.1.3 Case reviews

All investigated crashes are reviewed by a multi-disciplinary panel comprised of experts in human, vehicle, and road factors. The reviewers assess the completeness of data for each case, obtain an overall understanding of the crash, decide upon the most likely version of events, and identify the factors that contributed to the crash occurring. Additionally, potential interventions (or treatments) are nominated by the review panel and given a confidence level (high, medium, or low) that they would have prevented the crash.

Evidence collected over the course of an investigation informs the selection of human, vehicle, and road-based contributing factors. They cannot be selected based on speculation. Multiple contributing factors can be selected for each crash. Selection of human-based contributing factors, (e.g., fatigue) often relies on interview evidence, although statements made by crash participants regarding their own behaviour are not taken as fact and are judged against other statements and evidence from the scene. It should be noted that contributing factors relate to the crash occurring in the first place and do not consider factors that affect the severity of the crash.

As with the contributing factors, interventions that could have prevented the crash are grouped into those related to the human operator, vehicle, or road. Multiple interventions can be selected for each crash but each intervention is considered independently. The confidence level for a nominated intervention is selected based on knowledge of the probability of the intervention being effective under the specific circumstances of the crash. Again, prevention interventions relate to the crash occurring in the first place and do not consider interventions that could mitigate injury severity.

2.2 Coroner's reports on fatal crashes

CASR is granted access to reports on fatal crashes in SA by the state Coroner. Each file relates to an individual killed in a crash involving a motor vehicle (excluding single pedestrian and single bicyclist collisions) that occurred on a public road (excluding driveways and car parks). A single crash that killed several people would involve multiple files. Only completed ('closed') files (not currently undergoing a Coronial inquest or investigation) are obtained. Coroner's files include the following information:

- Official finding by the Coroner as to the cause of death.
- Official documentation that reports the death to the Coroner and briefly reviews some of the circumstances, such as collision dynamics and personal details of the deceased.
- Investigation by the Major Crash Investigation Unit of the SA Police. This includes a review of what occurred in the crash and all evidence (e.g., video footage, marks on road), participant/witness statements and interviews, medical history of deceased/accused, photos and details of the scene and vehicles, and a conclusion as to crash causation.
- Forensic pathology report on the post-mortem examination of the deceased. This includes the circumstances of death, significant injury findings, cause of death, and all observations by the forensic pathologist.
- Toxicology reports on the presence of alcohol and drugs in the deceased and any other road users involved who were aged 14 years or older.
- Examination reports for vehicles. These include conclusions on the overall condition of vehicles, details of any faults, and photos.

The files are reviewed by CASR experts in human, vehicle, and road factors. This involves creating an entry for each crash in a computer database and entering all important information from the files. All files for a multiple fatality crash are combined into a single crash entry in the database. Coronial data is linked to a database of police-reported crashes in SA, the Traffic Accident Reporting System. The experienced reviewers draw on their overall understanding of the crash to identify the factors that contributed to the crash occurring and nominate interventions that could have prevented the crash, in a process like that undertaken for in-depth case reviews (see Section 2.1.3).

2.3 Data analysis

Completed in-depth investigations were available for crashes that occurred between 2014 and 2019. Coroner's reports were available for crashes that occurred between 2014 and 2015. It should be noted that CASR investigations do not cover all times of the day (due to on-call periods) or all areas of the state (due to distance/time limitations on travel) in which a crash may occur. As such, they are not representative of all casualty crashes in SA. Coroner reports cover all fatal crashes in SA and are, therefore, representative. However, collection of these files by CASR is not quite complete, as it is not possible to obtain “open” files (i.e., currently undergoing a coronial inquest or investigation).

For the present study, researchers reviewed all available information about a crash and identified positive evidence that it involved driver fatigue. Such evidence included:

- The driver specifically stated in the interview that they fell asleep and crashed.
- The driver spoke to a family member/partner/friend prior to the crash (e.g., mobile phone) and reported that they were tired.
- The driver, or family member/friend/colleague, reported reduced or no sleep the previous night(s).
- The driver, or family member/friend/colleague, reported poor sleep health or general fatigue.
- The driver was undertaking driving outside of their normal routine.
- Witness reports of prior erratic driving (e.g., lane departures).
- Driver failed to respond quickly to an unexpected event.
- Footage from an in-vehicle camera that was focussed on the driver (installed in the vehicle as part of workplace procedure, with footage obtained as part of the Major Crash investigation), with the driver’s head and eyes showing signs of falling asleep prior to the crash.

As mentioned previously, statements made by crash participants regarding their behaviour were not necessarily taken as fact and were judged against other statements and evidence (e.g., crash type, vehicle movements).

Sometimes one piece of evidence was insufficient to identify fatigue, until it was combined with other evidence (e.g., friend reported driver had not slept the previous night and the driver drifted off the road into a tree with no corrective action). It was important that at least one of the factors that contributed to the crash was caused by the fatigued participant and was directly related to their fatigue (e.g., fell asleep and drifted into the oncoming lane), as a person can be fatigued without causing the crash they were involved in (e.g., they may be hit by another vehicle disobeying a red light). Note that a crash could have multiple contributing factors and would be selected if at least one of these was related to fatigue.

The characteristics of fatigue-related crashes were then examined in comparison to non-fatigue related crashes within the same datasets. Firstly, the crashes were examined in terms of the time of the day in which they occurred, the speed limit of the road where they occurred, their location (metropolitan or rural, intersection or midblock), whether they involved a single vehicle or multiple vehicles, and the error attributed to the crash by attending police.

The crashes were then analysed in terms of the role of fatigue (i.e., vehicle movements, crash type, lane departures, attempted corrective steering), the risk factors that led to fatigue (e.g., long distance driving, working night shift), and other general risk factors for crashes (e.g., unlicensed drivers, illegal blood alcohol concentration). The purpose of the trip that was being undertaken by the fatigued driver was also examined. Frequency counts, percentages, and chi-square tests (with an alpha level of 0.05 for statistical significance) were used.

Finally, the authors identified the interventions that could have prevented each crash by directly counteracting the causes of fatigue and/or the consequences and poor driving actions that result from fatigue. For example, workplace fatigue management directly attempts to stop drivers working long shifts without rest breaks and lane departure warnings alert a driver who has fallen asleep that the wheels of their car have drifted outside of lane markings. In comparison, some countermeasures may prevent a crash, such as suspending a driver’s licence for being medically unfit to drive but would only be nominated for the present study if they directly counteracted fatigue (e.g., if an individual's medical conditions, such as sleep apnoea, were directly associated with fatigue). Similarly, several drivers were unlicensed or tested positive for an illegal BAC or illicit drug but an unlicensed driver interlock or apprehension for drink or drug driving offence would not be nominated if there was no connection of these illegal behaviours to their fatigue. Apprehension for a drug driving offence was identified in some crashes in which the use of drugs directly caused fatigue (e.g., driver had been using methamphetamine and had not slept for several days).

3 Results

3.1 Contribution of driver fatigue to fatal and casualty crashes

The CASR team investigated and reviewed 254 casualty crashes between 2014 and 2019. The highest level of injury in each crash included: 1 (0.4%) treated by private doctor, 142 (55.9%) treated at hospital, 89 (35.0%) admitted to hospital, 19 (7.5%) fatal, and 3 (1.2%) unknown injury severity. Fatigue was a contributing factor in 11 crashes (4.3%). Data were collected from SA Coroner files for 156 fatal crashes between 2014 and 2015. Fatigue was a contributing factor in 18 (11.5%). It should be noted that two fatigue crashes investigated by CASR were fatal. These two fatal fatigue crashes were not in the data collected from the Coroner files as they both occurred in 2017. Although CASR crash investigations included a small number of fatal crashes, they are referred to as casualty crashes throughout the remainder of this report for simplicity, while crashes from Coroner reports are referred to as fatal crashes.

Figure 3.1 is a map of South Australia with the locations of all investigated fatigue crashes. The two CASR investigations that involved fatalities have been included in the black dots that represent fatal crashes. As such, Figure 3.1 displays 20 fatal crashes and nine of other injury levels. The two fatal crashes investigated by CASR occurred in the metropolitan area, while all fatal crashes detailed in Coroner reports occurred in rural areas. Figure 3.2 shows a closer view of the location of fatigue crashes in the Adelaide metropolitan area and surrounding regions.

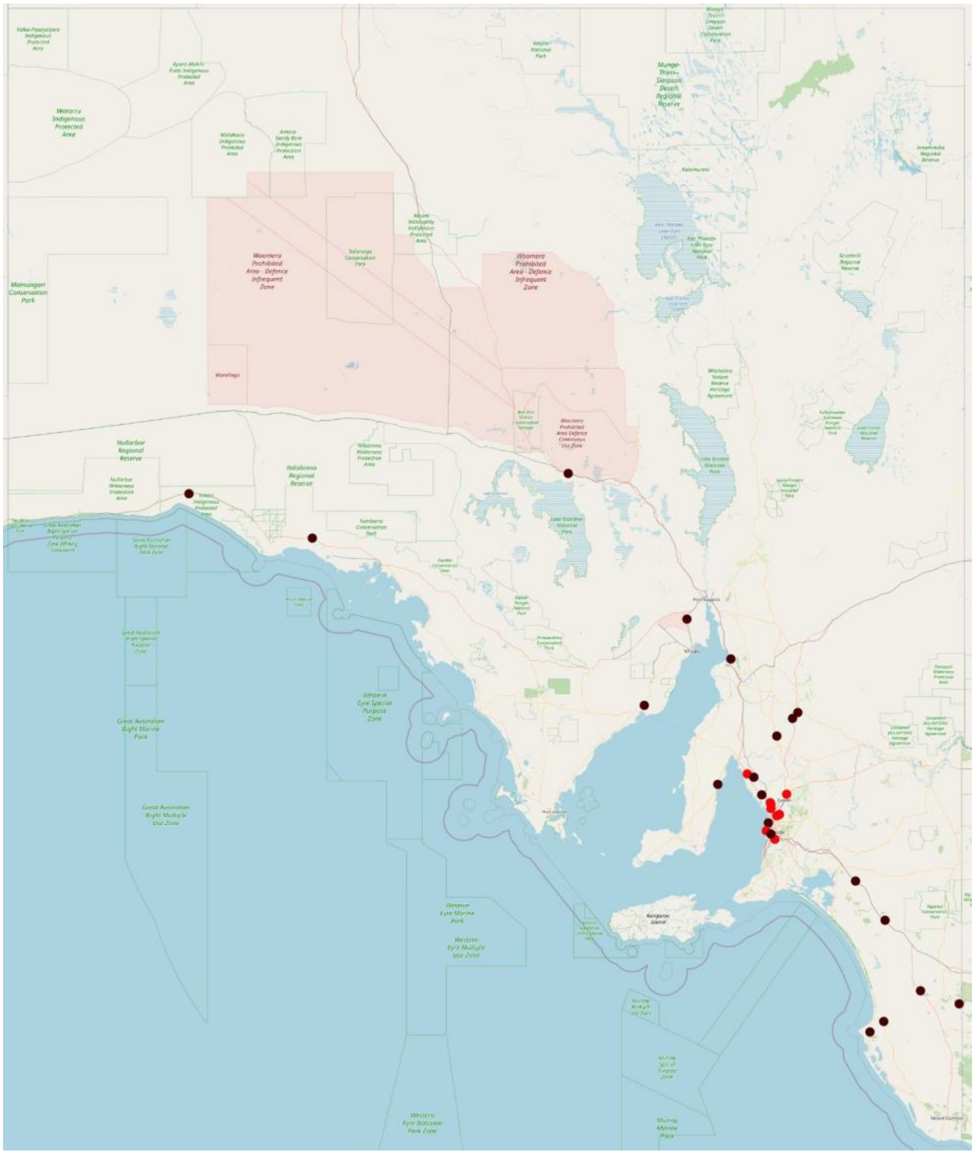

Figure 3.1
Map of South Australia showing the locations of casualty (red dots) and fatal (black dots) fatigue-related crashes

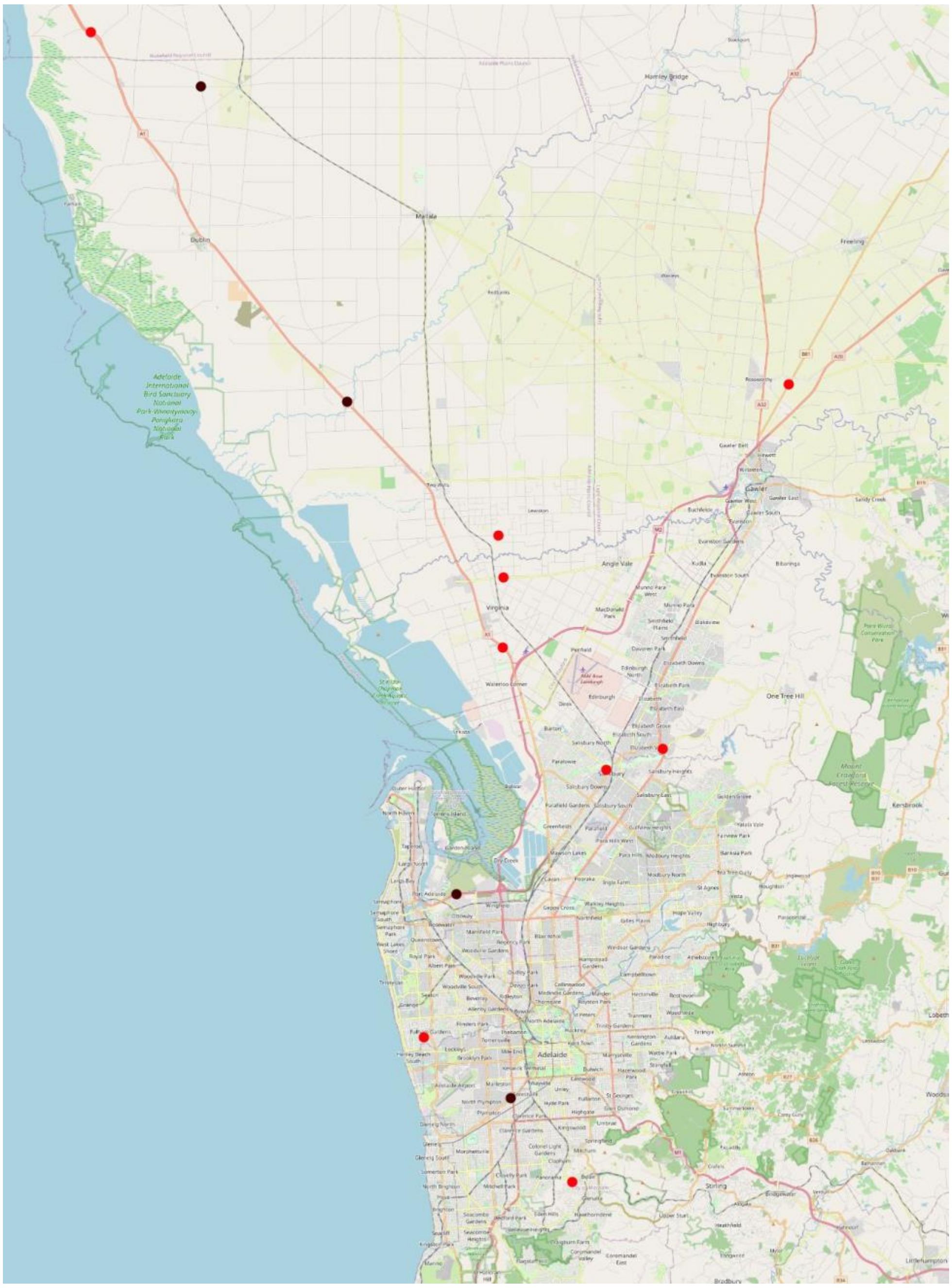

Figure 3.2
Closer view of Adelaide metropolitan area, surrounding regions, and the locations of casualty (red dots) and fatal (black dots) fatigue-related crashes

3.2 Role of driver fatigue and related risk factors in crashes

With respect to the characteristics of the fatigued drivers, nine (81.8%) of the fatigued drivers involved in the casualty crashes were male and two (18.2%) were female. Similarly, 14 (77.8%) of the fatigued drivers in the fatal crashes were male and four (22.2%) were female. In terms of the age of the fatigued drivers involved in the casualty crashes, one (9.1%) was between 16 and 24 years, seven (63.6%) were between 25 and 64 years, and three (27.3%) were 65 years or older (mean age was 44.4 years (SD = 20.9)). For fatal crashes, two (11.1%) fatigued drivers were aged between 16 and 24 years, 13 (72.2%)

were between 25 and 64 years, and three (16.7%) were 65 years or older (mean age was 49.8 years (SD = 18.5)).

3.2.1 Characteristics of fatigue crashes

The samples of 11 casualty and 18 fatal fatigue crashes were small. As such, the following analyses are only indicative of the role that fatigue plays in crash causation and the risk factors that lead to fatigue. Table 3.1 shows the characteristics of fatigue-related crashes in comparison to non-fatigue crashes, for both casualty and fatal crashes. There was no statistically significant difference by time of day in which the crashes occurred. Overall, fatigue and non-fatigue crashes in both data sets mostly occurred (72.4% for fatigue and 75.9% for non-fatigue) during daytime hours (06:00 to 17:59).

Almost two-thirds of casualty fatigue crashes occurred in areas with a speed limit of 80 to 110 km/h compared to 44% of non-fatigue casualty crashes. However, these differences were not statistically significant. All fatal fatigue crashes occurred on roads with speed limits of 80 to 110 km/h, compared to 65% of fatal crashes that did not involve fatigue. This difference was statistically significant. Overall, fatigue crashes were most likely to occur on high-speed roads. Consistent with this finding, all fatal fatigue crashes occurred in rural areas in comparison to 67% of non-fatigue fatal crashes, a difference that was statistically significant. There was no statistically significant difference by location for casualty crashes.

Casualty fatigue crashes were statistically significantly more likely to be single vehicle crashes and to occur at midblock locations than non-fatigue casualty crashes. However, there were no statistically significant differences for fatal crashes. When considering the vehicle movements in which a single vehicle typically departs its lane, consistent with the driver falling asleep, the crash types ‘head on’ and ‘single vehicle’ were grouped together and compared to all other crash types (including rear end, right angle, hit pedestrian, right turn, left turn etc.). Casualty fatigue crashes were statistically significantly more likely to be head on or single vehicle crashes than non-fatigue casualty crashes, which were more likely to be other types. Again, there were no statistically significant differences for fatal fatigue crashes. Of the seven single vehicle casualty crashes, five (71.4%) involved hitting a fixed object, one (14.3%) involved hitting a parked car and one (14.3%) involved the vehicle rolling over. Of the seven single vehicle fatal crashes, four (57.1%) involved the vehicle rolling over and three (42.9%) involved hitting a fixed object.

Table 3.1
Characteristics of casualty and fatal fatigue crashes, compared to non-fatigue crashes

Variable	Casualty fatigue crashes n = 11	Non-fatigue casualty crashes n = 243	Fatal fatigue crashes n = 18	Non-fatigue fatal crashes n = 138
Time of day				
00:00 to 05:59	0 (0.0%)	2 (0.8%)	2 (11.1%)	13 (9.4%)
06:00 to 11:59	3 (27.3%)	66 (27.2%)	7 (38.9%)	35 (25.4%)
12:00 to 17:59	4 (36.4%)	140 (57.6%)	7 (38.9%)	48 (34.8%)
18:00 to 23:59	4 (36.4%)	35 (14.4%)	2 (11.1%)	42 (30.4%)
Chi-square test		Not conducted		$\chi^2(3) = 3.3$, $p = .345$
Speed limit				
80 to 110	7 (63.6%)	107 (44.0%)	18 (100.0%)	88 (64.5%)
50 to 70	4 (36.4%)	136 (56.0%)	0 (0.0%)	50 (35.5%)
Chi-square test		$\chi^2(1) = 1.6$, $p = .201$		$\chi^2(1) = 9.6$, $p = .002$*
Location				
Rural	5 (45.5%)	104 (42.8%)	18 (100.0%)	92 (66.7%)
Metropolitan	6 (54.5%)	139 (57.2)	0 (0.0%)	46 (33.3%)
Chi-square test		$\chi^2(1) < 0.1$, $p = .862$		$\chi^2(1) = 8.5$, $p = .003$*
Single or multiple vehicle[a]				
Single	7 (70.0%)	74 (32.2%)	7 (38.9%)	61 (54.0%)
Multiple	3 (30.0%)	156 (67.8%)	11 (61.1%)	52 (46.0%)
Chi-square test		$\chi^2(1) = 6.1$, $p = .013$*		$\chi^2(1) = 1.4$, $p = .234$
Intersection or midblock				
Intersection	1 (9.1%)	103 (42.4%)	2 (11.1%)	31 (22.5%)
Midblock	10 (90.9%)	140 (57.6%)	16 (88.9%)	107 (77.5%)
Chi-square test		$\chi^2(1) = 4.8$, $p = .028$*		$\chi^2(1) = 1.2$, $p = .267$
Crash type				
Head on/single vehicle	10 (90.9%)	86 (35.4%)	13 (72.2%)	81 (58.7%)
Other	1 (9.1%)	157 (64.6%)	5 (27.8%)	57 (41.3%)
Chi-square test		$\chi^2(1) = 13.8$, $p < .001$*		$\chi^2(1) = 1.2$, $p = .270$

* $p < .05$

Note: Chi-square test not conducted when frequency count less than 5 in more than 25% of cells

[a] Crashes involving pedestrians and wheelchairs excluded. Crashes in which a vehicle collided with a parked vehicle categorised as single vehicle

The primary error causing each crash, attributed by police, is reported in Table 3.2. Chi-square tests could not be conducted as too many cells had frequency counts less than five. The most common errors for casualty fatigue crashes were inattention and fail to keep left, compared to inattention, fail to stand, and fail to give way for non-fatigue casualty crashes. The most common errors for fatal fatigue crashes were fail to keep left, inattention, and died sick or asleep at the wheel, compared to inattention, driving under the influence, and fail to keep left for non-fatigue fatal crashes. There were no police-attributed errors that were specifically related to fatigue for the casualty fatigue crashes. It might be expected that fatal fatigue crashes would be attributed to the category “died sick or asleep at the wheel” which includes crashes due to driver fatigue or medical issues; however, only four (22.2%) were.

Table 3.2
Primary error attributed by police to casualty and fatal fatigue crashes, compared to non-fatigue crashes

Police-attributed error	Casualty fatigue crashes n = 11	Non-fatigue casualty crashes n = 243	Fatal fatigue crashes n = 18	Non-fatigue fatal crashes n = 138
Inattention	7 (63.6%)	84 (34.6%)	4 (22.2%)	53 (38.4%)
Fail to keep left	3 (27.3%)	10 (4.1%)	7 (38.9%)	16 (11.6%)
Drunken pedestrian	1 (9.1%)	1 (0.4%)	0 (0.0%)	3 (2.2%)
Died sick or asleep at the wheel	0 (0.0%)	4 (1.6%)	4 (22.2%)	3 (2.2%)
Disobey – give way sign	0 (0.0%)	18 (7.4%)	2 (11.1%)	7 (5.1%)
Overtake without due care	0 (0.0%)	3 (1.2%)	1 (5.6%)	5 (3.6%)
DUI	0 (0.0%)	6 (2.5%)	0 (0.0%)	24 (17.4%)
Reverse without due care	0 (0.0%)	3 (1.2%)	0 (0.0%)	2 (1.4%)
Follow too closely	0 (0.0%)	18 (7.4%)	0 (0.0%)	2 (1.4%)
Disobey – traffic lights	0 (0.0%)	10 (4.1%)	0 (0.0%)	5 (3.6%)
Disobey – stop sign	0 (0.0%)	10 (4.1%)	0 (0.0%)	1 (0.7%)
Fail to give way	0 (0.0%)	26 (10.7%)	0 (0.0%)	7 (5.1%)
Fail to give way right	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.7%)
Fail to stand	0 (0.0%)	27 (11.1%)	0 (0.0%)	4 (2.9%)
Change lanes to endanger	0 (0.0%)	4 (1.6%)	0 (0.0%)	1 (0.7%)
Vehicle fault	0 (0.0%)	3 (1.2%)	0 (0.0%)	1 (0.7%)
Incorrect turn	0 (0.0%)	4 (1.6%)	0 (0.0%)	0 (0.0%)
Near side	0 (0.0%)	1 (0.4%)	0 (0.0%)	0 (0.0%)
Left off carriageway into object	0 (0.0%)	1 (0.4%)	0 (0.0%)	0 (0.0%)
Distracted	0 (0.0%)	2 (0.8%)	0 (0.0%)	0 (0.0%)
No error recorded	0 (0.0%)	8 (3.3%)	0 (0.0%)	3 (2.2%)

3.2.2 Role of fatigue in crash mechanisms

In terms of the role that fatigue played in the 11 casualty fatigue crashes, nine (81.8%) involved the driver falling asleep and the vehicle drifting out of the lane and either rolling over or colliding with a roadside object, parked vehicle or oncoming vehicle. Four of the nine (44.4%) departed their lane to the left and five (55.6%) to the right, while only two attempted corrective steering (which was exaggerated and led to the vehicle losing control in both crashes). In one exception to the lane departure crashes, the fatigued and distracted driver failed to see an alcohol intoxicated pedestrian crossing the road and, in the other, the driver overtook another vehicle by moving into the oncoming lane but failed to return to the correct lane and collided head-on with an oncoming vehicle.

Most of the fatal fatigue crashes (n = 15/18, 83.3%) also involved the driver falling asleep and the vehicle drifting out of the lane and either rolling over or colliding with a roadside object or oncoming vehicles. In two (13.3%) of these 15 crashes the vehicle departed its lane to the left and 13 (86.7%) to the right, while five attempted corrective steering (exaggerated and led to a loss of control in four cases). In two of the exceptions to the lane departure crashes, the drivers failed to give way at intersections and collided with other vehicles. In the other exception, the fatigued driver pulled off the road to left, with the left wheels on the gravel shoulder, and then commenced a right turn into a parking bay on the opposite side of the road. The driver turned directly across the path of another vehicle.

None of the casualty fatigue crashes involved heavy vehicles, while ten (55.6%) of the fatal fatigue crashes did. However, the truck driver fell asleep and was deemed to be at-fault in only two (20.0%).

3.2.3 Risk factors for fatigue crashes

The preceding circumstances of the fatigued drivers in each of the 11 casualty and 18 fatal crashes were examined and grouped into meaningful categories of fatigue risk factors (Table 3.3). Note that one crash could involve several risk factors, so the sum of these factors is larger than the number of crashes. Also note that there had to be evidence (e.g., driver/witness statement) of a risk factor; they were not based on speculation. The most common risk factors for fatigue in casualty crashes were illicit drug use, medication use and abnormal work/sleep hours. The most common risk factor for fatal crashes was long distance driving. A driver was considered to have driven a long distance if they had travelled approximately 150 kilometres or further before the crash occurred (which roughly equates to a two-hour journey for a vehicle travelling at 100 km/h, when taking into consideration that the vehicle will likely have to slow during the journey for other vehicles, intersections, areas with lower speed limits (e.g., towns, road work zones), etc., and is consistent with public education campaigns that recommend drivers take a break after every two hours of driving). It should be noted, however, that a further three drivers had travelled less than 150 kilometres when they crashed and so were not considered to have driven a long distance but had planned overall journeys of 150 kilometres or further. The other most common risk factors were no, minimal, or broken sleep on the night(s) leading up to the crash and a history of fatigue-related health conditions (e.g., Parkinson's Disease, sleep apnoea, diabetes mellitus).

Two fatigued drivers were unlicensed (7.4% of 27 drivers for whom licence status was known) and one fatigued driver had an illegal BAC (3.7% of 27 drivers for whom blood alcohol concentration was known). Seven (24.1%) fatigued drivers tested positive for an illicit drug (four for methamphetamine, two for cannabis and one for cocaine).

The vehicles of the fatigued drivers (casualty and fatal) were grouped according to whether they contained a single occupant (the driver only) or multiple occupants. They were then compared to the numbers of single and multiple occupant vehicles of non-fatigued drivers across the entire sample of crashes (several vehicles from a single crash would be included, making the number of vehicles larger than the number of crashes). Pedestrians were excluded, as were motorcycles, bicycles, and gophers/wheelchairs, as they do not generally carry more than one person. For vehicles driven by fatigued drivers, there were 18 (62.1%) with a single occupant and 11 (37.9%) with multiple occupants. For comparison vehicles, there were 367 (66.4%) with a single occupant and 186 (33.6%) with multiple occupants. The difference between the groups was not statistically significant ($\chi 2(1) = 0.2$, $p = .633$).

Table 3.3
Risk factors for fatigue in casualty and fatal crashes

Risk factors	Frequency
Casualty crashes (n = 11)	
Illicit drug caused fatigue (e.g., cannabis before driving, no sleep due to methamphetamine)	4
Medications led to fatigue (e.g., benzodiazepine use, polypharmacy)	3
Abnormal work/sleep (ongoing routine or no/minimal sleep night before)	3
Ongoing poor sleep health – medications that affect sleep	2
Ongoing poor sleep health – general (e.g., insomnia, light sleeper)	1
Medical conditions led to fatigue (e.g., narcolepsy)	1
Life stressors before driving	1
Fatal crashes (n = 18)	
Long distance driving	12
No/minimal/broken sleep night/s leading up to crash	8
History of fatigue related health conditions (e.g., diabetes mellitus)	4
Mental health/life stressors affecting ability to sleep	3
Abnormal work/sleep (ongoing routine or no/minimal sleep night before)	2
Long period of physical labour before driving	2
Life stressors before driving	2
Illicit drug caused fatigue (e.g., no sleep due to meth)	1
Medications led to fatigue (e.g., benzodiazepine use, polypharmacy)	1

Table 3.4 lists the purposes of the trips that the fatigued drivers were undertaking when they crashed. Fourteen (48.3%) crashes occurred when the fatigued driver was undertaking a trip involving every day or leisure activities. Three (10.3%) occurred when the fatigued driver was at work, with long distance driving involved in two (one driver was travelling a long way to pick up supplies for their business without rest breaks, the other was a truck driver working a night shift after driving all through the previous night), while the other involved a fatigued taxi driver working an evening shift in metropolitan Adelaide. Four (13.8%) occurred while the fatigued driver was travelling to or from work, with three returning home after work (one after working during the night and then driving a long distance, one after working an early morning shift, and the other after working as a builder all day in the hot sun and then driving a long distance) and the other travelling to work (over a much longer distance and heading off a lot earlier in the morning than usual). It should also be noted that two crashes (6.9%) occurred while the drivers were undertaking personal trips (travel for holiday in one and the trip purpose was not clear in the other) but were fatigued after working night shifts. Trip purpose was not identified for seven crashes (24.1%).

Table 3.4
Purpose of trip for fatigued drivers (casualty and fatal crashes combined)

Trip purpose	Frequency
Travel/holiday	4
Travelling to/from work	4
Returning home general (i.e., not from work)	4
Various everyday tasks (e.g., shopping, banking, doctor appointment)	3
Recreation/socialising	3
Work	3
Other	1
Unknown	7
Total	29

3.3 Countermeasures for fatigue crashes and their potential effectiveness

Countermeasures or interventions that could have potentially prevented the fatigue-related crash from occurring are listed in Table 3.5. The number and proportion of crashes (casualty and fatal) that could have been prevented and the category of the countermeasure are also listed. More than one countermeasure could be listed for each crash. The two most common countermeasures were lane support system vehicle technologies: lane keep assist and lane departure warning (could have prevented 79.3% and 65.5% of crashes respectively). The third most common was drowsiness detection/warning (55.2%), followed by audio tactile centre lines (41.4%) and autonomous emergency braking (34.5%). Separated road, audio tactile edge line and collision warning were also deemed to prevent more than a quarter of the crashes. Four of the five most common countermeasures were related to vehicle technology. Although the provision of roadside rest areas along long-distance routes is a common method to reduce fatigued driving and the related crash risk, there was not enough evidence related to these crashes to recommend that rest areas would have been an effective countermeasure (e.g., it could not be determined whether the driver had actually stopped at a rest area prior to the crash, had passed a rest area without stopping, or had rested at another location such as a service station).

Table 3.5
Most common interventions for preventing fatigue crashes

Interventions	Number prevented	%	Prevention area
Lane keep assist	23	79.3	Vehicle technology
Lane departure warning	19	65.5	Vehicle technology
Drowsiness detection/warning	16	55.2	Vehicle technology
Audio tactile centre lines	12	41.4	Road design
Autonomous emergency braking	10	34.5	Vehicle technology
Separated road	9	31.0	Road design
Audio tactile edge line	8	27.6	Road design
Collision warning	8	27.6	Vehicle technology
Apprehension for drink/drug driving offence	5	17.2	Enforcement
Electronic stability control	5	17.2	Vehicle technology
Licence suspension for being medically unfit to drive	4	13.8	Medical/licensing
Wide centre median (5m+)	4	13.8	Road design
Clearzone to guidelines	4	13.8	Road design
Better medical control/advice regarding medication	2	6.9	Medical/licensing
Sealed shoulders	1	3.4	Road design
Prevent right turn	1	3.4	Road design
Right turn lane	1	3.4	Road design
Stop sign	1	3.4	Road design
Traffic lights	1	3.4	Road design
Roundabout	1	3.4	Road design
Vertical deflection	1	3.4	Road design
Grade separated junction	1	3.4	Road design
Workplace fatigue management	1	3.4	Work health/safety
Centre barrier	1	3.4	Road design

4 Discussion

The purpose of this report was to examine the contribution of driver fatigue to casualty and fatal crashes in SA, the role that fatigue played in individual crashes, the risk factors that led to the fatigue, and the countermeasures that could have prevented the fatigue crashes. The key findings are discussed in the following sections.

4.1 Contribution of driver fatigue to crashes

Findings from this study revealed that driver fatigue contributed to 4.3% of casualty crashes and 11.5% of fatal crashes in South Australia. The incidence of fatal crashes involving fatigue in South Australia is lower than estimates for fatal crashes in New South Wales (16.5%) in 2014 (NSW Centre for Road Safety, 2015). It is similar, however, to estimates reported in Western Australia for 2017 – fatigue contributed to approximately 10% of road users killed (Road Safety Commission, 2018) – and in New Zealand between 2014 and 2016 – fatigue was involved in around 12% of fatal crashes (Ministry of Transport, 2017). The estimate for fatigue in casualty crashes is much lower than the figure of 20 to 30% for casualty crashes in Australia estimated by the Australian Transport Council (2011). It should be reiterated, however, that crash investigations by CASR are not representative of all casualty crashes in South Australia, as they do not cover all times of the day or all areas of South Australia in which a crash may occur. This may have lowered the number of fatigue-related crashes that were investigated and included in the estimate (particularly crashes during late night and early morning hours).

The criteria for identifying driver fatigue – clear evidence that it was involved – was stringent and without speculation. Therefore, these estimates are conservative and could be an underestimate. Fatigue may have contributed to other crashes but without clear evidence this could not have been identified. This method of identifying fatigue from detailed crash investigations is more conservative than using an operational definition of a fatigue-related crash (based on simple crash information) to search databases and produce an estimate. However, it is free from generalised assumptions about fatigue crashes, which are inherent to operational definitions, and the varying definitions between jurisdictions and studies. Overall, the present purpose was to conduct an exploration of fatigue crashes, in the absence of other studies, as a platform for further research. Therefore, the present estimates of fatigue in casualty and fatal crashes should be considered conservative base estimates. It should be noted, however, that crash investigations, information, and databases of the type used in this report are not always available, and many authorities and researchers rely on mass crash databases with basic information to inform their estimates of fatigue.

The limitations of basic crash information were also highlighted. None of the errors attributed by police to the casualty fatigue crashes mentioned fatigue. Similarly, a majority did not mention fatigue as the primary error for fatal crashes, although several were attributed to the driver error of ‘died sick or asleep at the wheel’. This could be due to difficulty in identifying driver fatigue and, as a result, a reluctance to note it as a cause of the crash due to possible consequences if fatigue is incorrectly identified (e.g., legal consequences if a driver is found to be responsible for the crash). The error listed is the primary error associated with the crash. It may be that fatigue is listed as a secondary or subsequent error. In the interests of accurately recording fatigue as a driver error, it would be useful to separate medical illness and fatigue into two separate error categories. Also, police attributions of fatigue may be different in other jurisdictions. For example, Cercarelli and Haworth (2002) found police in Western Australia correctly identified fatigue in crashes approximately 75% of the time. In the present study, inattention was the most common error across all casualty crashes and non-fatigue fatal crashes (fail to keep left was the most common for fatal fatigue crashes). It has been noted that many causes of, or errors involved in crashes, including fatigue-related crashes, are routinely attributed to inattention (Horne &

Reyner, 1999). This complicates the use of such information to quantify the incidence of fatigue in crash statistics.

4.2 Characteristics of fatigue crashes

Most fatigue crashes occurred on high-speed roads and at midblock locations. This is consistent with other findings of the present study, such as that all fatal fatigue crashes occurred on rural roads (although two crashes in the in-depth casualty crash investigation data set involved fatalities that occurred in metropolitan areas), that the most common risk factor for fatal fatigue crashes was long distance driving and that most fatigue crashes from both datasets involved lane departure followed by a rollover or colliding with a roadside object or oncoming vehicles. It is also consistent with other research. For example, in New Zealand between 2014 and 2016, around 96% of fatigue-related fatal crashes were found to have involved a single vehicle loss of control/run off road or head on crashes (Ministry of Transport, 2017). It is interesting that so many occurred at midblock locations, which probably reflects the task-engagement required of drivers at intersections to make decisions and react to stimuli, while driving midblock (particularly in rural areas) requires less engagement and so drivers may settle into more automatic processing and a lower level of arousal.

This study demonstrates that the common pattern for fatal fatigue crashes is that they occur on high-speed rural roads, involve lane departure, and are most likely the result of a driver fatigued from long distance driving. That all fatal fatigue crashes occurred on high-speed rural roads (excluding the two fatal CASR in-depth crash investigations that occurred in metropolitan areas) is likely due to the increased impact speed of crashes on these roads and the resulting fatal consequences. Casualty fatigue crashes, however, appear to be more varied. Half of the casualty fatigue crashes occurred in metropolitan areas. Therefore, the present findings are consistent with research by Armstrong et al. (2008) who found that while fatigue crashes most often occur in rural, high-speed driving environments with a single vehicle leaving the roadway or crossing the centre line, fatigue also contributes to a broad range of crashes, including those in low-speed, urban environments (approximately 1 in 3 fatigue crashes occurred in these areas in the Armstrong et al. study).

Also interesting is that most fatigue crashes occurred during daylight hours (63.7% for casualty crashes and 77.8% for fatal crashes) and only two fatal crashes (6.9% of all fatigue crashes) occurred between midnight and 6am. This contradicts assumptions made by many operational definitions, and the findings of many studies (e.g., Armstrong et al., 2008; Horne & Rayner, 1995a; Sagberg, 1999), that fatigue crashes mostly occur at night. Horne and Reyner (1995a) found that at around 6am, drivers are over 20 times more likely to fall asleep at the wheel than at around 10am. Sagberg (1999) found that the odds of a crash being fatigue-related increased by a factor of six if the crash occurred between midnight and 6am. However, Dawson et al. (2018) have pointed out that people can be fatigued at any time of the day. Any operational definitions that assume that fatigue crashes occur during times when people generally sleep would have missed many crashes identified in this study. It is acknowledged that the small number of night-hour fatigue casualty crashes might result from these hours not being covered as comprehensively by the CASR crash investigation protocol (investigations cover 9am to 9pm weekdays, although fatal and life-threatening crashes outside these hours are followed-up). The Coroner reports cover all fatal crashes that occur in South Australia.

This study also demonstrated that, although not common, fatigue crashes involving pedestrians, unlicensed drivers and alcohol intoxicated drivers do occur and would be missed by operational definitions that excluded them. These findings suggest that fatigue can impair driving performance and lead to crashes in many ways (Armstrong et al., 2008, Dawson et al., 2018)

4.3 Risk factors for fatigue

The benefit of the present exploration of risk factors for driving fatigue is that it can be used to inform public education messaging. Attempts to address fatigued driving should focus on the most common risk factors identified in this study – individuals who are driving long distances and those who have reduced sleep the night/s before driving. Other precursors to fatigue – illicit drugs, abnormal work and sleep routines, fatigue-inducing medication, and a history of fatigue-related health conditions – should also be acknowledged. Public messaging may not work, however, for certain drivers at risk of fatigue, such as those using illicit drugs. The relationship between the use of illicit drugs and driver fatigue could be explored further. Information about the effects of fatigue on driving should be provided by general practitioners when prescribing fatigue-inducing medication or treating fatigue-related health conditions. Mass media education and promotion campaigns targeting driver fatigue should be utilised in metropolitan areas as well as rural areas.

In 24% of crashes, the fatigued driver was working or travelling to/from work. There were also several crashes in which the driver was fatigued after working night shifts. This highlights the importance of fatigue management for working drivers. In a workplace context, research indicates that fatigue management and an active safety culture are the best measures to address professional driver fatigue (Goldenbeld & Nikolaou, 2019). Fatigue management is a fundamental aspect of workplace safety within the heavy vehicle sector and is a legislated component of the Heavy Vehicle National Law (HVNL) in Australia. Fatigue management includes practices and policies such as maximum work requirements, minimum rest requirements, work diary requirements, technology to monitor and alert drivers of fatigue, and ongoing education around fatigue. While fatigued driving has previously been associated with the crashes of heavy vehicles drivers (Palamara, 2016), it was not found to be the case in this study. Ten (55.2%) fatal fatigue crashes involved heavy vehicles but the heavy vehicle driver fell asleep and was at-fault in only two (20.0%). None of the casualty crashes involved heavy vehicles. It could be that the mandated fatigue management in this industry is having the desired effect.

While the heavy vehicle industry mandates fatigue management, there are no requirements in other industries or workplaces and so responsibility is dependent on employers. There is a need for greater employer responsibility and the promotion of strategies to manage driver fatigue in workplaces (Gander, Hartley, Powell, Cabon, Hitchcock, Mills, et al., 2011). Education is also important for fleet safety and for professions that undertake a lot of driving (e.g., tradespeople). Education initiatives should reinforce the risks and consequences of driving while fatigued, particularly when driving long distances and working long shifts (and travelling home afterwards or even driving the next day).

4.4 Countermeasures for fatigue

This study highlighted the countermeasures that could have potentially prevented the fatigue crashes investigated. Four of the top five most effective interventions related to Advanced Driver Assist vehicle technologies (lane keep assist, lane departure warning, drowsiness detection/warning and autonomous emergency braking). A road infrastructure treatment, audio tactile centre lines (i.e., raised or grooved line markings that alert the driver when they are deviating over the centre line), was the fourth most effective intervention. Individually, the top five interventions could have each prevented at least a third of the crashes (34.5% prevented by autonomous emergency braking) up to a maximum of 79.3% of crashes potentially prevented by lane keep assist.

The two most effective interventions (lane keep assist and lane departure warning) attempt to prevent lane departure by fatigued drivers. Lane keep assist is potentially more effective than lane departure warning as it takes corrective action to keep the vehicle within the lane, rather than providing merely a warning. Encouraging consumers to purchase vehicles with such technology could potentially prevent the majority of fatigue-related crashes. One way to improve the uptake of these technologies is the provision of an Australian Design Rule (ADR) requiring manufacturers to include lane support technology in all new vehicles. However, it can take around a decade in Australia for such technology to permeate into a large proportion of vehicles in the driving population once an ADR is implemented (Anderson, Hutchinson, Linke, & Ponte, 2011; Australian Automobile Association, 2017). The Australasian New Car Assessment Program (ANCAP), as well as Used Car Safety Ratings (UCSR) can also inform and potentially motivate consumers (both private and fleet vehicles) to purchase the safest vehicles they can afford, particularly those with technology that can prevent fatigue-related crashes. While many fatigue crashes occurred in rural areas, there are difficulties in promoting safe vehicles to drivers in these areas due to lower socio-economic status and a preference for vehicles that are 'fit for purpose' (e.g., utilities) rather than those that contain relevant safety features (Austroads, 2019b; McIntosh, 2012).

Audio tactile line marking (used on the centre and edges of the roads) is not as expensive to implement as other road treatments, such as barriers (centre and side of road), separated roads, and clear zones, because they can be installed without any changes to the existing roadway cross-section (Neuman et al., 2003). Audio tactile line marking can be targeted to locations where there is a higher risk of fatigue crashes.

The present study examined countermeasures or treatments that could have prevented the crashes occurring. However, there are also many countermeasures that can reduce, or mitigate, injury severity in the event of a fatigue-related crash, particularly barriers (centre and side of road), higher levels of occupant protection in newer vehicles (e.g., multiple airbags, impact protection) and reductions of speed limits. Centre and side barriers are a countermeasure for lane-departure fatigue-related crashes, as they physically prevent vehicles entering the opposite lane or departing the side of the road. However, they were considered as an injury mitigating countermeasure rather than a crash prevention countermeasure, as the vehicle would still collide with the barrier, but the injury severity would be considerably lower than a head on, rollover, or hit fixed object crash. It should also be reiterated that, although there was not enough evidence to recommend that roadside rest areas would have been an effective countermeasure to the crashes investigated for this report, it is a common view that they can reduce the risk of crashes due to fatigue when regularly provided along long-distance routes (Queensland Government, 2014; Austroads, 2019a).

4.5 Effectiveness of countermeasures for preventing fatigue crashes

The effectiveness of the countermeasures identified in this study for preventing fatigue crashes have been documented in the research literature. These studies are briefly reviewed in the following sections for the top five most effective countermeasures identified in the present study.

4.5.1 Lane keep assist

Lane keep assist (LKA) technology helps drivers to maintain their vehicle's lane position and avoid lane departure type crashes (identified in this study as the most common type of fatigue-related crashes). If the vehicle departs its lane without having signalled an intention to do so, LKA will automatically take corrective action to move the vehicle back into the lane (Mehler, Reimer, Lavalliere, Dobres, & Coughlin, 2014). For these systems to successfully operate, however, they need to accurately detect road lane markings. Such markings may not always be optimal, or even present, in rural and remote areas where fatigue-related crashes are most common (Palamara, 2016). Research from the U.S by Scanlon, Kusano, Sherony, & Gabler (2015) has estimated that LKA systems with autonomous steering inputs that were light, moderate or aggressive reduce lane departure crashes by between 32.7% and 37.3%. They also estimated that systems with fully autonomous steering reduce lane departure crashes by

51%. Research from Sweden by Sternlund, Strandroth, Rizzi, Lie, & Tingvall (2017) has examined the effectiveness of systems that include LKA and lane departure warnings (see Section 4.5.2). LKA and lane departure warning technology are often fitted as part of the same in-vehicle system. Sternlund et al. (2017) estimated that these systems reduce head-on and single-vehicle injury crashes by 53% on roads with speed limits between 70 and 120 km/h and with dry or wet road surface (i.e., not covered by ice or snow), and by 30% for all speed limits and road surface conditions.

4.5.2 Lane departure warning

Lane departure warning (LDW) technology provides audio and visual warnings to the driver when their vehicle drifts or departs its lane without having signalled an intention to do so (Thompson, Mackenzie, Dutschke, Baldock, Raftery, & Wall 2018). The driver is then required to correct the position of the vehicle by moving it back into its lane to avoid a lane departure type collision. Research from the U.S. by Cicchino (2017a) indicated that vehicles fitted with LDW have an 86% reduction in fatal lane departure crashes compared to vehicles without the technology. Scanlon et al. (2015) estimated that LDW systems reduce lane departure crashes by 26.1%. In a retrospective study of the crash involvement of trucks in the U.S., Hickman et al. (2015) found that the trucks without LDW had an LDW-related crash rate 1.9 times higher than trucks with LDW. Also, research by Thompson et al. (2018) trialled LDW technology in government fleet vehicles in New South Wales, Australia, and found that it led to an improvement in lane keeping (reduction in non-signalised lane departures) by the drivers. Improvements in lane keeping, fewer lane departures, and increased turn-signal use were also found in a trial of LDW technology in passenger vehicles in the U.S. by Sayer et al. (2011).

4.5.3 Drowsiness detection/warning systems

These systems detect drivers who are drowsy or falling asleep and then provide warnings (e.g., audio, visual, haptic). A review by Sikander and Anwar (2018) found that a combination of multiple detection features (e.g., head and eye positions, facial expression, steering input, lane deviation, speed variations and steering wheel grip pressure sensors) provide the most accurate and reliable fatigue detection results. Time of day, duration of drive and driver characteristics could also be included in these systems. Driver characteristics are important due to individual differences in fatigue patterns and cognitive performance, which affects the accuracy and reliability of these systems (de Naurois, Bourdin, Bougard, & Vercher, 2018). However, Sparrow, LaJambe, and Van Dongen (2019) noted that no independent scientific evaluations of drowsiness detection systems exist. Importantly, this technology provides guidance and can only be effective if the driver complies with the warning and stops driving for a rest break (Searson, Ponte, Hutchinson, Anderson, & Lydon, 2014). Sikander and Anwar (2018) concluded that further advancements are necessary before this technology can perform accurately in actual driving conditions.

4.5.4 Audio tactile lane markings

Audio tactile lane markings (sometimes referred to as rumble strips or raised profile lines) involve raised or grooved patterns and can be used on the centre and edge lines of the road (Austroads, 2016). They provide a humming sound and vibration when a vehicle’s tyres run over them. This indicates to the driver that they have departed their lane. Various studies have shown that audio tactile centre lines reduce head on crashes by 20 to 50% and all crashes by 10 to 15% (Austroads, 2016; Austroads, 2010; Harkey et al., 2008; Hirasawa, Takada, Asano, & Saito, 2006; Kar & Weeks, 2009; Persaud, Retting, & Lyon, 2004; Sayed, deLeur, & Pump, 2010; Torbic et al., 2009). However, the crash prevention of audio tactile centre lines is even greater when combined with audio tactile edge lines (Olson, Sujka, & Manchas, 2013). Roads with audio tactile centre and edge lines have been found to produce a 65% reduction in lane-departure (including head on and run-off-road) crashes (Olson et al., 2013). As such they are both a low-cost (see Section 4.4) and effective countermeasure (Austroads, 2016; Olson et al., 2013). To be most effective, however, it is also important that audio tactile centre lines are combined with wider centre medians (e.g., one metre (Austroads, 2018)) between lanes of opposite direction and audio tactile edge lines are combined with sealed road shoulders, so that drivers have room to correct any lane departures.

4.5.5 Autonomous emergency braking

Autonomous emergency braking (AEB) automatically brakes the vehicle when it detects an obstacle (e.g., tree, pedestrian, another vehicle) in the vehicle's forward travel path. In so doing, it has the capacity to prevent forward collisions. However, it has only had a limited availability in the new car market in Australia. Only 3% of new vehicles for sale in Australia in 2015 included AEB as a standard safety feature but this has improved to 31% at the beginning of 2018 (ANCAP, 2018).

Research has shown that early versions of AEB, which were designed for lower speed metropolitan environments, could reduce rear-end police-reported crashes by 35 to 41% (Fildes et al., 2015; Rizzi, Kullgre, & Tingvall, 2014). More recent variants of AEB function in high-speed conditions, such as rural and remote roads, by using long range radar to detect obstacles up to 200 metres away (Austroads, 2019b). Unfortunately, at the time or writing, the authors could not identify any studies that examine the effectiveness of high-speed AEB systems for preventing fatigue-related crashes in rural or remote areas. However, Cicchino (2017b) found that vehicles fitted with low-speed (up to 19 mph) AEB systems had a 43% lower involvement in front-to-rear crashes, while those fitted with AEB that operates at higher speeds had a 50% lower involvement, compared to vehicles without these systems for crashes in 22 U.S. states between 2010 and 2014.

4.6 Study limitations

As mentioned previously, in-depth crash investigations by CASR are limited in reach. They do not cover all times of the day (due to on-call periods) or all areas of the state (due to distance/time limitations on travel) in which a crash may occur. As such, they are not representative of all casualty crashes in South Australia.

Another limitation was the small number of fatigue crashes from which the role and risk factors of fatigue were examined. While they were a representation of fatigue crashes that occurred over a two-to-four-year period, a small sample is difficult to draw conclusions from. Future research could examine a longer time frame.

4.7 Conclusions

This study was the first, of which the authors are aware, to estimate the contribution of driver fatigue to crashes within South Australia. It was revealed that fatigue contributed to 4.3% of casualty crashes and 11.5% of fatal crashes in South Australia (based on a conservative estimate). This study also builds on and supports the previous limited research into fatigue crashes by providing a broad understanding of the mechanisms through which fatigue contributes to crashes and the risk factors for driving while fatigued. The characteristics of fatigue-related crashes identified in this research and examination of the contributing role of fatigue assists in the targeting and messaging of public education campaigns. For example, the findings suggest messaging should target metropolitan and rural areas, with long distance driving a target behaviour (particularly in rural areas, on high-speed roads). Driver fatigue resulting from the use of illegal drugs or prescription medication could be explored further. This study also, importantly, identified that vehicle technologies (e.g., lane keep assist, lane departure warning) are likely to be the most effective countermeasures for preventing fatigue crashes.

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