

Driver behaviour preceding crashes at stop or give way sign-controlled intersections

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Abstract

Right-angle crashes, in which a driver fails to give way to another road user, are common at stop and give way sign-controlled intersections. This report investigated the driver behaviour and circumstances that lead to these crashes. Casualty crashes investigated by the Centre for Automotive Safety Research (CASR) in South Australia (2014-present) were analysed. At-fault drivers in 57 right-angle crashes did not statistically significantly differ from those in 375 other types of crashes in their likelihood of testing positive for alcohol or drugs or having passengers. Their vision of the other road user was restricted in 26 crashes. In 33, they slowed or stopped at the intersection before moving into the path of the other road user (16 looked-but-failed-to-see). In 19, they proceeded straight into the intersection without slowing or stopping, and the most common circumstance for these drivers was that they were unfamiliar with the road (11 crashes). Crash histories of the 50 intersections across SA at which right-angle crashes were investigated by CASR were examined and more than 20 right-angle crashes occurred at each of ten intersections (three had 30 or more) during the prior ten years. Safety can be improved through superior intersection design (e.g., grade separation to remove conflict) and treatments that increase driver awareness of the intersection or reduce crash forces to within human biomechanical tolerance to harm. Practical considerations, such as treatment costs and predicted effectiveness, are also important.

Keywords

Right-angle crashes, stop/give way signs, intersections, countermeasures, safe system design.

Citation

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Summary

Intersections are a fundamental and necessary component of the road system. However, they create conflict points between vehicles travelling in the same and from opposite directions and on adjacent roads. Many intersections are controlled by stop or give way signs, which require decision-making and judgement by the driver and, therefore, have a high potential for human error. Right-angle crashes, in which two vehicles approaching the intersection from adjacent roads collide when one driver fails to give way, are common at stop and give way sign-controlled intersections. This report investigated the driver behaviour and circumstances that precede such crashes to gain an understanding of why they occur.

In-depth at-the-scene investigations of casualty crashes conducted by the Centre for Automotive Safety Research (CASR) in South Australia from 2014 to present were analysed. The narratives, details, and circumstances of right-angle crashes at stop or give way sign-controlled intersections were examined. The design and crash history of the specific intersections where crashes were investigated by CASR were also examined. Additionally, the insights that were gained through these examinations were used to guide an exploration of the countermeasures that could be most effective at preventing these crashes or reducing the resulting injury severity.

The at-fault drivers in the right-angle crashes did not statistically significantly differ from at-fault drivers in other types of crashes in their likelihood of testing positive for alcohol or drugs, or of having passengers in their vehicles. This suggests that these crashes were not more likely than other crashes to result from risky driver behaviour such as driving while under the influence or distracted but, rather, that they mostly resulted from driver error and external factors. This latter conclusion is based on the following findings:

- In 33 crashes, they slowed or stopped at the intersection before moving into the path of the other road user, suggesting that they were aware of the intersection and their requirement to give way, but another factor contributed to the crash (e.g., they looked but built-up traffic blocked their vision of the other vehicle). Looked-but-failed-to-see errors contributed to 16.
- In 19 crashes, they proceeded straight into the intersection without slowing or stopping, which suggests that they were completely unaware of their requirement to give way, or unaware that they were approaching an intersection. The most common preceding circumstance for these drivers was that they were unfamiliar with the road (11 crashes).
- The at-fault driver's vision of the other road user was restricted in 26 right-angle crashes.

The prior ten-year crash histories of the 50 individual intersections across SA at which right-angle crashes were investigated by CASR were examined and more than 20 right-angle crashes had occurred at each of ten intersections (three had 30 or more). This suggests that these crashes continue to occur at many intersections, often despite considerable intersection upgrades and crash prevention treatments being applied. Based on these findings, further safety improvements to both planned and existing intersections can be achieved through superior design that aligns with safe system principles (e.g., grade separation to remove conflict) and treatments that increase driver awareness of the intersection (e.g., rumble strips on the approach) or reduce crash forces so that they do not exceed the human biomechanical tolerance to harm (e.g., reducing the speed of vehicles). However, practical considerations, such as the cost of potential treatments, predicted effectiveness, and optimising traffic flow, are also important.

Note that this report was substantially completed in November 2023 and does not consider developments after that date.

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1. Introduction

Intersections are a fundamental and necessary component of the road system. However, intersections create conflict points between vehicles travelling in the same and from opposite directions and on adjacent roads. Research by Mongiardini, Elsegood, and Stokes (2021) examined police-reported crashes in South Australia from 2013 to 2019 and found that intersection crashes account for approximately 50% of crashes in the Adelaide metropolitan region and 25% of crashes outside of the metropolitan area. Due to the stringent warrants and relatively high cost of installing traffic signals and roundabouts, a substantial number of intersections are controlled by stop or give way signs. The problem with this method of intersection control is that it requires a higher level of involvement and judgement by the driver, who must slow or stop, look for other vehicles, and then decide whether it is safe to traverse the intersection. This increases the potential for human error.

Right-angle crashes (also commonly referred to as lateral direction crashes), in which two vehicles approaching the intersection from adjacent roads collide, are the most common type of crashes at non-signalised intersections (Mongiardini et al., 2021; Stokes & Woolley, 2022). Ragland and Zabyshny (2003) analysed more than 1.5 million intersection crashes across the USA and found that over 82% were lateral direction type crashes. They also found that 70% of crashes at two-way stop sign controlled intersections were of right-angle configuration and that 45% of crashes resulted when both vehicles on the major and minor road attempted to travel straight through the intersection. Similarly, Souleyrette, Tenges, McDonald, and Maze (2005) found that 82% of crashes at rural stop sign controlled intersections in Iowa, USA were right-angle crashes.

Right-angle crashes generally occur at stop and give way sign-controlled intersections due to two distinct types of error made by the driver. In the first, the driver stops or slows for a stop or give way sign, looks in the necessary direction(s), then continues straight through the intersection or turns left or right onto the adjacent (intersecting) road, but fails to recognise another road user (e.g., due to visual obstruction or low vehicle conspicuity) approaching on the adjacent road or misjudges their speed. This first type of error can occur at T-intersections (where a minor road terminates at a major road) and crossroad intersections (where both the minor and major roads continue straight through the intersection, but traffic on the minor road must give way to traffic on the major road). The crashes that result from this type of error are often referred to as fail to give way crashes. In the other type of error that causes these crashes, the driver is completely unaware of their need to give way to other traffic. The vehicle continues straight into the intersection and the driver is often unaware that they have done anything wrong until they collide with another road user. This second type of error predominantly occurs at crossroad intersections. The crashes that result from this second type of error are often referred to as run-through crashes. These mechanisms of crashes at non-signalised intersections have been demonstrated in the literature. Preston and Storm (2003) observed 530 right-angle crashes at stop sign-controlled crossroad intersections in the USA and found that 57% involved a vehicle that had stopped at the stop sign before entering the intersection. Twenty-six percent of the right-angle crashes involved a vehicle travelling through the intersection without stopping (the mechanism in 17% of crashes could not be determined).

There are many preceding driver factors and circumstances that can contribute to right-angle crashes at stop and give way sign-controlled intersections. For example, a driver may not be familiar with the intersection and may be distracted, or the weather (e.g., dark, heavy rain) may be such that the driver does not see the stop or give way sign. A greater understanding of why these crashes occur

could highlight the most effective treatments and interventions to prevent them. For example, if a driver checks but fails to recognise an oncoming vehicle due to a visual obstruction, improved sight distance at the intersection would be beneficial. However, if a driver travels straight through a stop sign due to distraction, advanced warning signs or an off-set travel path through the intersection may be beneficial.

The purpose of this report is to undertake a thorough exploration of the driver behaviour and circumstances preceding right-angle crashes at stop and give way sign-controlled intersections to gain an understanding of the most common reasons why these crashes occur. To this end, it is necessary to examine detailed narratives of what happened in such crashes (e.g., statements/interviews with participants/witnesses). This level of detailed information is not available in many crash databases (e.g., police-reported crash databases). However, in-depth at-the-scene crash investigation conducted by the Centre for Automotive Safety Research (CASR) does provide the necessary information. The report also examines the intersections where these types of crashes were investigated by CASR in South Australia to determine whether there were any characteristics of these locations that could have contributed to the occurrence of the crashes (e.g., complicated intersection design, visibility issues). Additionally, the insights that were gained through these examinations are used to guide an exploration of the countermeasures that could be most effective at preventing these crashes or reducing the resulting injury severity.

2. Method

This chapter of the report outlines the methods currently undertaken for in-depth crash investigations by the Centre for Automotive Safety Research (CASR) in South Australia (SA), as well as the analyses of the data that were undertaken for the present study.

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

In-depth, at-the-scene casualty crash investigation is one of the principal research activities at CASR. The current series of in-depth investigations in SA have been conducted by CASR from November 2014 to present. The main purpose of the activity is to build an informative and accurate database of injury crashes, so that the factors that contribute to casualty road crashes and injuries can be established, and potential solutions identified.

2.1.1. Attending a scene and investigating a crash

A crash investigation commences when the CASR crash team identifies that the SA Ambulance Service has dispatched an ambulance to a road crash. Two investigators then immediately drive to the crash location. They attend a metropolitan crash if it is located in the city of Adelaide or the surrounding suburbs, within a 30-minute drive from the Adelaide central business district (CBD). They attend a rural crash if it is located within a 100-kilometre radius (approximately 1.5-hour drive) from the CBD. Travel limitations based on time and distance were established so that evidence at the scene is likely to be preserved when the team arrive. The 30-minute time metropolitan time limitation is shorter than the 1.5-hour rural time limitation because CASR investigators discovered that evidence is cleared more quickly from the scene of metropolitan crashes (tow trucks have shorter distances to travel, police clear the scene quickly to get busy intersections and traffic flowing again). Additionally, a rural crash will not be attended if it is located within a rural township. Road conditions and speed limits in rural townships are like city and suburban areas and are already captured in metropolitan investigations. 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 motorbikes but excluding single pedestrians and single bicyclists).

When the current series of in-depth crash investigation commenced in 2014, the team would be on call to immediately attend crashes during two shifts – 9 am to 2 pm and 2 pm to 9 pm – Monday to Friday. The earlier shift was changed, however, in October 2019 to 7 am to 2 pm to capture morning peak-hour traffic times and improve the representativeness of the sample of crashes. Saturday shifts of 7 am to 9 pm and Sunday shifts of 9 am to 9 pm were also introduced. It should be noted that the analyses of the present report include crashes investigated both before and after the change in shift times. In addition, fatal and life-threatening crashes occurring outside of shift times, which were attended by the Major Crash Investigation Unit of the SA Police, were investigated in the following days, as the evidence is preserved by Major Crash (vehicles held, photos taken of scene, scene marked). The result, however, is that crashes included in the database that occurred outside of shift times have a bias towards high severity. CASR aims to investigate 50 individual crashes per year.

CASR investigators perform the following tasks when they arrive at the scene of a 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 (e.g., tyre marks); and
- record videos from the direction of travel of each road user actively involved (physical contact) in the crash.

The following information is obtained after investigators have attended the scene:

- the police report,
- the Coroner's report (if fatal),
- the forensics report (alcohol and drug test results),
- the previous crash history of the location of the crash (based on police-reported crash data in the Traffic Accident Reporting System (TARS) that is processed and maintained by the South Australian Department for Infrastructure and Transport (DIT)),
- detailed information on the vehicles involved from online car databases (e.g., dimensions, engine power, safety features/technology/ratings),
- detailed participant injury information (linked to hospital and ambulance records),
- the crash and offence history of drivers and motorcycle riders 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.

2.1.2. Participant/witness interviews

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

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

It should be noted that data are collected for in-depth crash investigation at CASR with the understanding that they are confidential and are never to be shared. This is particularly important for interviews because it reassures crash participants that they can provide us with information with the knowledge that it will only be used for the purposes of deidentified research.

2.1.3. Event Data Recorders

Many makes and models of vehicles in Australia contain Event Data Recorders (EDRs). EDRs detect when a crash has occurred and log the last few seconds of important data prior to the crash. This pre-crash data – which can include travel speed, impact speed, restraint use, brake/accelerator pedal position, crash impact severity (delta- v), deployment of safety features (e.g., airbags), and steering wheel angle – can be downloaded. CASR investigators download these data from compatible vehicles either immediately at the scene of a crash or when they follow-up vehicles that have been taken from the scene by the owners, a tow truck, or the Major Crash Investigation Unit of the SA Police.

2.1.4. Case reviews

A multi-disciplinary panel comprised of experts in human, vehicle, and road factors review all investigated crashes. The reviewers consider the completeness of data for each case, obtain a holistic understanding of the crash, decide upon the most likely version of events, and determine 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.

2.2. Data analysis

In-depth investigations of right-angle crashes at stop or give way sign-controlled intersections in which a driver moved into the path of another vehicle due to failing to recognise the oncoming vehicle or failing to adequately slow or stop for the sign were included in the analysis for the present study. The narratives, details and circumstances of the crashes were examined. As noted above, 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 and should, instead, be considered case studies. It should also be noted that statements made by crash participants regarding their behaviour are not necessarily taken as fact and are judged against other statements and evidence (e.g., vehicle movements and damage). Frequency counts and chi-square tests (with an alpha level of 0.05 for statistical significance) were used for the analyses.

3. Results

3.1. Sample of crashes

The total number of crashes that were examined for this study was 57. Of these, 37 occurred at give way sign-controlled intersections and 20 occurred at stop sign-controlled intersections. Fourteen occurred at T-intersections and 43 occurred at crossroad intersections. Thirty-seven involved at least two passenger vehicles (e.g., car, SUV, station wagon, van, taxi, etc.), while 14 involved at least one passenger vehicle and a heavy vehicle, three involved a passenger vehicle and a motorcycle, two involved a passenger vehicle and a bicycle, and one involved two heavy vehicles.

Table 3.1 presents the characteristics of the sample of right-angle crashes in which a driver failed to obey a stop or give way sign in comparison to other casualty crashes in the CASR in-depth crash investigation dataset ($n = 375$). Pedestrian versus vehicle crashes were excluded from the comparison sample due to the unprotected nature of pedestrians, their vulnerability to injury, and the sample of right-angle crashes not including any pedestrian collisions. Right-angle crashes at uncontrolled (no signs) intersections, traffic lights and roundabouts were also removed from the comparison sample, as they are too similar to right-angle crashes at stop or give way sign-controlled intersections in terms of crash angles and dynamics for the purposes of comparison.

Two-thirds of the right-angle crashes occurred in fine weather conditions and these weather conditions did not statistically significantly differ from those for all other crashes. Right-angle crashes also did not significantly differ from the other crashes in location (both crash categories were approximately evenly divided between metropolitan and rural locations) and injury severity (around one-third of the crashes in both categories involved serious or fatal injuries). However, the two crash categories did significantly differ in the speed limit where the crash occurred, with right-angle crashes more likely to occur in areas with speed limits of 70, 80 or 90 km/h and other crashes more likely to occur in areas with speed limits of 100 or 110 km/h.

3.2. Crash causation

The at-fault drivers (those who failed to obey the stop and give way signs) in the right-angle crashes included 22 females and 35 males. Eleven were aged between 16 and 24 years, 35 were between 25 and 64 years, and 11 were 65 years or older.

Thirty-seven of the at-fault drivers were sole occupants of the vehicle and 20 had passengers. Two hundred and thirty-seven of the at-fault drivers (at-fault motorcyclists, bicyclists, scooter riders, and gopher/wheelchair users were excluded as they do not generally carry more than one person) in the other casualty crashes in the CASR in-depth crash investigation dataset were sole occupants of the vehicle and 79 had passengers. The difference between the groups was not statistically significant ($\chi^2(1) = 2.5$, $p = .112$).

Table 3.1
Characteristics of right-angle casualty crashes at stop and
give way sign-controlled intersections, compared to other casualty crashes

Variable	Right-angle crashes	Other crashes
Weather conditions		
Fine	39	246
Overcast/wind/rain/fog	18	127
Chi-square test	$\chi^2(1) = 0.1, p = .713$	
Location		
Metropolitan	23	185
Rural	34	190
Chi-square test	$\chi^2(1) = 1.6, p = .206$	
Speed limit		
40/50/60 km/h	28	169
70/80/90 km/h	22	91
100/110 km/h	7	109
Chi-square test	$\chi^2(2) = 9.1, p = .010^*$	
Injury severity		
Not seriously injured (no injury/hospital treated)	38	222
Seriously injured (hospital admission/fatal)	19	146
Chi-square test	$\chi^2(1) = 0.8, p = .361$	

* $p < .05$

Of the 47 at-fault drivers for whom blood alcohol concentration (BAC) was recorded, only two were positive (both were over the legal BAC limit of .05 grams/100 mL). By contrast, 22 of the 275 at-fault road users (including at-fault motorcyclists, bicyclists, scooter riders, and gopher/wheelchair users) in the comparison sample of crashes for whom BAC was recorded were positive (17 were over .05 grams/100 mL BAC, four were under .05 grams/100 mL, and one tested positive but their exact BAC was not provided). The difference between the groups was not statistically significant ($\chi^2(1) = 0.8, p = .366$). Additionally, five of the 27 at-fault drivers in right-angle crashes for whom drug screening results (tests for THC, methamphetamine and MDMA or 'ecstasy') were known tested positive (three for THC and two for meth). By contrast, 37 of the 228 at-fault road users (including at-fault motorcyclists, bicyclists, scooter riders, and gopher/wheelchair users) in the comparison sample of crashes for whom drug results were known tested positive (17 for THC, 17 for meth, two for both THC and meth, and one tested positive but the drug was not specified). Again, the difference between the groups was not statistically significant ($\chi^2(1) = 0.1, p = .762$).

In 19 of the crashes, the at-fault driver proceeded straight into the intersection without slowing or stopping, which suggests that they thought they were on the priority road and were completely unaware of their requirement to give way, or unaware that they were approaching an intersection. All 19 of these run-through crashes occurred at crossroad intersections, as the non-priority road

continues on the other side of the intersection (compared to T-intersections where the non-priority road terminates, and it should be clear to the driver that their road ends). In 33 of the total sample, the at-fault driver slowed or stopped at the intersection, suggesting that they were aware of the intersection and their requirement to give way (but then another factor contributed to their failure to give way and the crash, such as the driver looked but did not register an approaching road user on the priority road, or their vision of the approaching road user was blocked by something, or they misjudged the speeds of other road users and gaps in traffic). Information as to whether the at-fault driver slowed, stopped, or went straight through the intersection was unavailable in five crashes.

In six crashes, the driver slowed and looked for approaching vehicles but did not slow to a speed that would be sufficiently slow to safely check for traffic. The at-fault driver's direction of traffic was controlled by a give way sign in four of these crashes and by a stop sign in two.

There were factors that affected the at-fault driver's vision of approaching vehicles or bicycles in 26 crashes. Table 3.2 lists these factors and the number of crashes in which they were present. Note that one crash could involve several factors affecting visibility, so the sum of these factors is larger than the number of crashes. Vision of the approaching vehicle or bicycle that the at-fault driver collided with was most often blocked by other vehicles on the intersecting road that were approaching the intersection, already passing through the intersection, parked on the side of the road, turning at the intersection, or built-up (and stationary or slowly moving) through the intersection. The other most common factors that affected visibility related to sun glare in the driver's eyes, trees, bushes, or foliage on the side of the road, the colour of the other vehicle or road user being difficult to see (e.g., grey), and when rain restricted the driver's vision.

Table 3.2
Factors that affected vision of approaching vehicles or bicycles in right-angle casualty crashes at stop and give way sign-controlled intersections

Factor that affected vision of approaching vehicle or bicycle	Frequency
Vehicles on intersecting road (approaching, passing, parked, turning, or built-up traffic)	8
Sun glare	4
Roadside trees, bushes, and foliage	4
Conspicuity (colour) of other vehicle/road user	4
Inclement weather	4
Road signs	3
Darkness/night time	3
Parts of the at-fault vehicle (e.g., A-pillars, side mirrors)	3
Roadside embankment	2
Crest or rise in intersecting road	1
Bend in intersecting road close to intersection	1

3.2.1. Preceding behaviour and circumstances of drivers

A clear explanation of the preceding behaviour and circumstances of the drivers who travelled straight into the intersection without slowing or stopping for the stop or give way sign was available (either through an interview with the driver or descriptions provided at the scene by the driver, the police, or witnesses) for 12 crashes (of the 19 crashes of this type – referred to as run-through crashes). This information was examined and grouped into meaningful categories in Table 3.3. Again, one crash could involve several meaningful preceding behaviours/circumstances, so the sum for these categories is larger than the number of crashes.

Not surprisingly, the driver was unfamiliar with the road in 11 of the 12 run-through crashes. There was not enough information about the driver in the twelfth crash to determine whether they were familiar with the road or not. The second most common circumstance was that the crash occurred in dark lighting conditions that made it difficult for the driver to see the intersection or the stop/give way sign. Inclement weather contributed to three crashes for the same reason. In four crashes, the stop/give way line at the intersection was faded or not present. The road had recently been resurfaced in one crash, but a give way line had not been painted on the new surface and the driver noted that this contributed to them not being aware that they had to give way at the intersection (Figure 3.1).

Table 3.3
Preceding behaviour and circumstances of drivers who travelled straight through the intersection without slowing or stopping for the stop or give way sign ($n = 12$)

Preceding behaviour and circumstances	Frequency
Unfamiliar with road	11
Dark lighting conditions	5
Stop/give way line marking faded or not present	4
Inclement weather (rainy/wet conditions)	3
General route confusion/driver lost	2
Distraction (e.g., mobile phone use, talking to passenger)	2
Driver drug positive, and it likely contributed to the crash	1
Speed too high for conditions (e.g., on a dirt road)	1
Mental health condition	1
Sun glare	1
Following another vehicle that also went straight through intersection	1



Figure 3.1

Intersection in which the non-priority road had recently been resurfaced but a give way line had not been repainted. A driver approaching the intersection from this direction travelled straight through without realising they were required to give way and collided with another vehicle.

Information relating to the preceding behaviour and circumstances of the drivers who slowed or stopped at the intersection to give way, but then moved into the path of an approaching road user on the priority road was available for 29 crashes (of the 33 crashes of this type – referred to as fail to give way crashes) and is presented in Table 3.4. The driver in 16 of these crashes slowed or stopped at the intersection and looked for traffic but failed to detect an approaching road user despite nothing affecting their vision (commonly referred to as ‘looked-but-failed-to-see’ crashes). In three crashes, the driver saw the approaching road user but misjudged their speed, their distance, or the available gap between approaching traffic. In six crashes, the driver’s vision of the approaching road user was blocked by a dynamic visual obstruction (other vehicles on the priority road in all six crashes including left turning vehicles and built-up traffic). In four crashes, the driver’s vision was blocked by static features of the road environment (including road signs and parked vehicles) or parts of the interior of their own vehicle (including side mirrors and A-pillars). There was not enough information about the driver in four crashes to determine why they moved into the path of an approaching road user despite slowing or stopping at the sign. There were also a range of other factors that contributed to these crashes that are listed in Table 3.4. It should be noted that several contributing factors could be present in a crash (e.g., the primary cause of a crash could be a ‘looked-but-failed-to-see’ error, but an intersection visibility issue could also place additional attentional demands on the driver that would contribute to the failure to see the other road user, or the primary error could be misjudgement of approach speed but fatigue could contribute to the error). The most common additional contributing factors were related to sun glare affecting the driver’s vision and the conspicuity of the other road user (related to dark colour). It is also worth noting that the approaching road user (the not at-fault road user involved in the crash) was either a motorcyclist (two crashes) or a cyclist (two crashes) in four of the 16 ‘looked-but-failed-to-see’ crashes. There was also a not at-fault motorcyclist involved in one of the four crashes in which the driver’s vision was blocked by a static element (in that case, parked vehicles).

Table 3.4

Factors that contributed to crashes in which the at-fault driver slowed or stopped for the stop or give way sign and looked for traffic, but then moved into the path of an oncoming road user on the priority road ($n = 29$)

Contributing factors	Frequency
Driver looked-but-failed-to-see	16
Dynamic visual obstruction (other vehicles on the priority road)	6
Static visual obstruction (e.g., road signs, parked vehicles, side mirrors)	4
Driver misjudged speed, distance, or available gap of traffic	3
Sun glare affected vision	3
Conspicuity of approaching road user	3
Driver illegal BAC	2
Driver drug positive	2
Intersection visibility issues due to trees, embankments, corners, etc.	2
Driver distracted by dropping something in the vehicle	1
Driver distracted by life events	1
Driver unfamiliar with vehicle/did not accelerate as fast as expected	1
Driver fatigue	1
Reckless driving (slowed for stop sign but did not stop and adequately check for traffic)	1

3.3. Crash locations

Figure 3.2 displays the locations in South Australia where the right-angle crashes at stop and give way signs occurred. They are coloured green for T-junctions and pink for crossroad intersections. Not surprisingly, the largest cluster of crashes occurred in the city of Adelaide and surrounding suburbs, where there are larger numbers of roads, intersections, and vehicles. However, there were other clusters of crashes, predominantly at crossroad intersections, around the town of Nuriootpa in the Barossa Valley, in the McLaren Vale area, and the area covering Angle Vale, Virginia and Two Wells. Interestingly, these areas are peri-urban areas that border the suburban areas of Adelaide and mark the transition to the rural areas of SA. Angle Vale, Virginia and Two Wells, in particular, consist of square, grid-system road networks with many crossroad intersections that involve roads that do not have roadside buildings, businesses, houses or infrastructure, that would otherwise serve as a visual cue to distinguish between priority and non-priority roads (Figure 3.3).

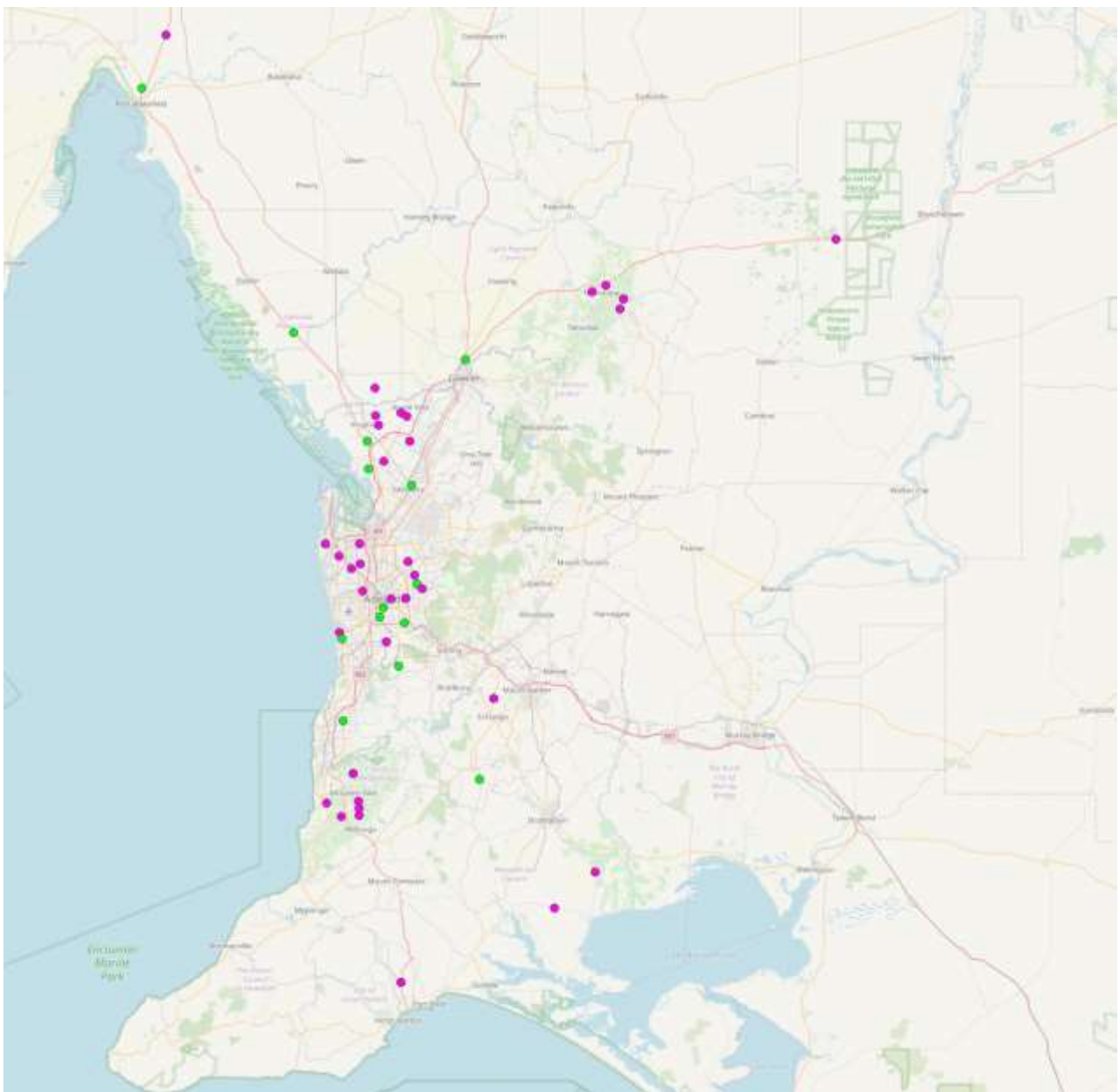


Figure 3.2

Map of Adelaide and surrounding regions showing the locations of right-angle crashes at stop and give way sign-controlled T-junction (green dots) and crossroad intersections (pink dots)



Figure 3.3

Typical intersection in the peri-urban area of Angle Vale, Virginia, and Two Wells. Three crashes were investigated by CASR at this location (Section 3.3.1) and more than 20 crashes occurred here over a ten-year period (Section 3.3.2).

In 12 of the 19 run-through crashes, there were advanced warning signs on the approach. This is interesting because the driver must have missed these clearly visible warning signs that have been installed, in addition to the standard stop or give ways signs, for the express purpose of increasing the awareness of drivers that they are approaching an intersection at which they are required to give way. Further to this, the intersections had additional treatments to further improve driver awareness in several of the 12 crashes. In one, the words “prepare to stop” were written on the advanced sign (Figure 3.4), and the two stop signs at the intersection (one on each side of the road) were bordered by a yellow/orange colour to further improve conspicuity. The single stop sign at the intersection was again bordered by yellow/orange in another crash, while one crash had two advanced warning signs (one on each side of the road), warning delineation on the approach and two give way signs at the intersection (one on each side of the road) that were bordered by yellow/orange. The non-priority road (on which drivers were required to give way) was off-set through the intersection in two crashes. The intention of off-set intersections is that the non-priority road does not continue in a straight line through the intersection. This serves as a visual indication to the driver that they are not on a priority road and must give way. One of these off-set intersections included a bi-directional chevron sign at the termination of the non-priority road from the perspective of the at-fault driver (Figure 3.5). However, despite these additional treatments designed to increase driver awareness, the drivers in these crashes managed to drive straight into the intersections without slowing or stopping.



Figure 3.4

Advanced warning sign that was missed by a driver who travelled straight into the intersection



Figure 3.5

Bi-directional chevron sign in the path of an off-set non-priority road through an intersection

Figure 3.6 presents a heat map of the locations by the severity of the crash (non-injury = yellow dots, hospital treated = orange dots, hospital admitted = red dots, fatal = black dots). Not surprisingly, non-injury crashes and those in which the highest level of injury was hospital treatment were concentrated around the city and suburban areas. In comparison, crashes in which a participant was admitted to hospital or fatally injured as a result were more common in rural areas, where speed limits (and therefore vehicle speeds) were higher through the intersections. Hospital admission and fatal crashes were common in the McLaren Vale area.

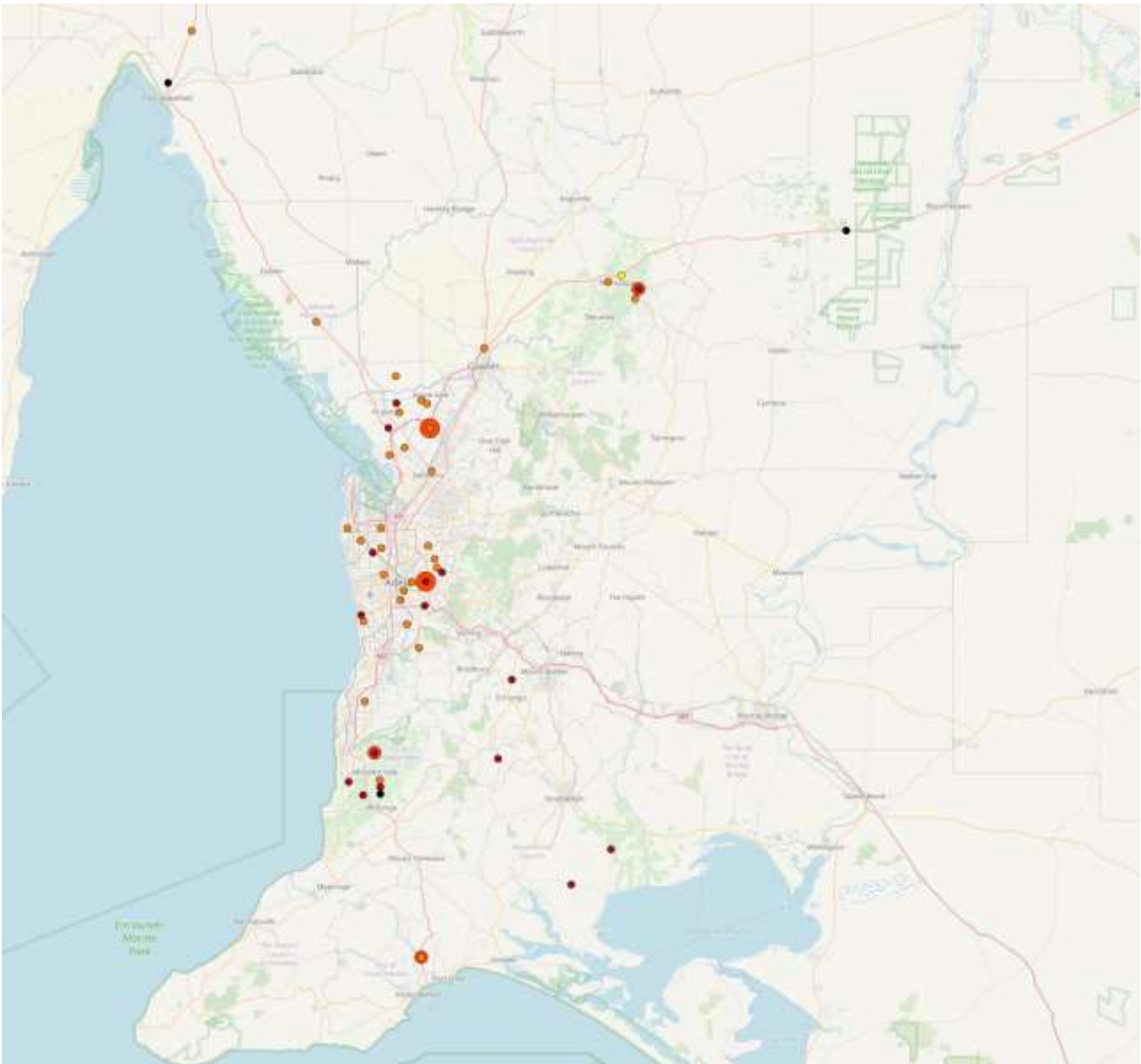


Figure 3.6

Map of Adelaide and surrounding regions showing the locations of right-angle crashes at stop and give way sign-controlled intersections, by crash severity (non-injury = yellow dots, hospital treated = orange dots, hospital admitted = red dots, fatal = black dots)

3.3.1. Locations with multiple crashes investigated by CASR

Figure 3.6 also identifies five specific intersections where multiple crashes were investigated by CASR (larger dots where more than one crash occurred). Three intersections had two crashes investigated at them and two intersections had three. Each of these locations will now be discussed in detail.

Two crashes were investigated at the crossroad intersection of Penrice and Stockwell Roads in Light Pass, in the Barossa Valley. The first occurred in 2018 and the second four-and-a-half years later in 2022. In the first, a work utility was heading north on Stockwell Road and a two-axle truck was heading west on Penrice Road. The intersection was controlled by stop signs for both directions on Penrice Road. The truck driver stopped at the intersection and gave way to a B-double truck heading north on Stockwell Road. The driver's view further down the road was blocked, however, by a rise in Stockwell Road on the approach to the intersection for traffic travelling north, and possibly by a large tree on the south-east corner of the intersection. He drove across the intersection in front of the utility. In the second crash, a B-double truck was heading north on Stockwell Road and a dual-cab utility was heading east on Penrice Road (opposite direction from the truck in the first crash). The utility driver drove straight through the intersection without slowing or stopping and checking for traffic. The driver stated that he was not aware that he had to stop due to never having driven through the intersection before. Also, the sun glare reflecting off the wet road and the rainy and overcast conditions contributed to his failing to notice the signs. The speed limit through the intersection for both roads is 80 km/h. The highest level of injury for the first crash was hospital treatment and for the second it was hospital admission. Interestingly, in the four-and-a-half years between the two crashes, the intersection had been identified as a black spot and several treatments were applied to improve driver awareness on Penrice Road that they must stop and look for traffic. In 2018, both directions of Penrice Road had an advanced warning sign and two stop signs at the intersection (Figure 3.7). In 2022, delineation, a tear-drop median, and a 'keep left' sign had been added to off-set Penrice Road (Figure 3.8). Despite these treatments, the driver in the latter crash drove straight through.



Figure 3.7
Penrice Road through the intersection with Stockwell Road in Light Pass in 2018,
facing west from the eastern side of the intersection



Figure 3.8

Penrice Road through the intersection with Stockwell Road in 2022, facing east from the western side of the intersection

Two crashes were investigated at the crossroad intersection of Seaview and Olivers/Coppermine Roads in McLaren Vale. The first occurred in 2019 and the second four years later in 2023. In both, one vehicle (a 3-axle truck in the second crash) was heading west on Seaview Road and another was heading north on Olivers Road. The vehicles on Olivers Road in both crashes went straight through the intersection without slowing or stopping. In the first crash, the driver on Olivers Road who went straight through the intersection was an international traveller who had been in Australia for less than 24 hours and was unfamiliar with the intersection. The driver had driven through two previous intersections on Olivers Road for which he had right of way (priority road) and, therefore, thought he also had right of way at the intersection with Seaview Road (despite an advanced warning give way ahead sign). It is not known why the driver in the second crash drove straight through the intersection. The speed limit for both roads is 80 km/h. The highest level of injury for the first crash was hospital treatment and for the second crash was hospital admission. Once again, in the period between the two crashes several treatments were applied to the intersection. At the time of the first crash, there was one warning give way ahead sign on the approach and one give way sign at the intersection for vehicles on Olivers Road (Figure 3.9). At the time of the second crash, there were two warning give way ahead signs (one on either side of the road) with the distance to the intersection displayed (Figure 3.10). There was also delineation on the bitumen within the approaching lane to further draw the driver's attention to the intersection ahead and two give way signs at the intersection (one on either side of the road) that were bordered by a yellow/orange colour to increase conspicuity. These additional treatments did not stop the driver in the second crash travelling straight through without stopping.



Figure 3.9

Olivers Road through the intersection with Seaview Road in 2019, facing north from the southern side of the intersection



Figure 3.10

Olivers Road through the intersection with Seaview Road in 2019, facing north from the southern side of the intersection

Two crashes at the crossroad intersection of Victor Harbor and Hindmarsh Tiers/Virgin Roads in Hindmarsh Valley were also investigated by CASR. There was only a one-and-a-half-month period between them, so the intersection had not changed. In the first crash, a car was heading east on

Hindmarsh Tiers Road. The driver was distracted by talking to the front seat passenger and had taken a wrong turn from his usual route. He was, therefore, unfamiliar with the road and generally confused as to where he was. He was intending to turn right onto Victor Harbor Road to head south but did not think he had reached the intersection yet. He thought he was on a priority road and did not see the give way sign until the last moment (he also missed an advanced warning give way ahead sign). He hit the brakes but slid on the wet road into the intersection and into the path of a car heading north on Victor Harbor Road. A car in the second crash was approaching the intersection on Hindmarsh Tiers Road in the same direction as the car in the first crash and was intending to turn right to travel south on Victor Harbor Road. The driver stopped at the intersection and looked for approaching vehicles but his view to the right was blocked by a vehicle heading north on Victor Harbor Road that had entered a slip lane to turn left and travel west on Hindmarsh Tiers Road. This turning vehicle was blocking the view of another vehicle behind it continuing north on Victor Harbor Road. The driver in the car that had stopped and was checking for traffic assumed it was clear and moved into the intersection and the path of the car behind the turning vehicle. The speed limit for both roads is 100 km/h. The highest level of injury for both crashes was hospital treatment.

Three crashes were investigated at the crossroad intersection of Womma and Andrews Roads in Penfield, which is close to Virginia and Angle Vale. They occurred over a period of almost five years (two in 2018 and one in 2023). No changes were made to the intersection. In both directions on Andrews Road (the non-priority road) there was an advanced warning give way ahead sign and two give way signs at the intersection (one on the left side of the road and one in the safety bars in-between the lanes of opposite directions). However, in the most recent crash in 2023, the give way sign in the safety bars at the intersection had been knocked over and removed. The vehicle on Andrews Road was heading southwest in two crashes and northeast in the other. The vehicle on Womma Road was heading northwest in two crashes and southeast in the other. The driver on Andrews Road slowed for the intersection in one crash (then edged his way through a gap in built-up traffic going one direction but this traffic blocked his view of a vehicle approaching in the far lane of Womma Road), stopped in one crash (but sun glare blinded his vision of an approaching vehicle that he moved into the path of), and went straight through in the other (no details why). The speed limit for both roads is 80 km/h. The highest level of injury in two crashes was hospital treatment and in the other it was hospital admission.

Additionally, three crashes were investigated at the metropolitan crossroad intersection of Kensington Road and George Street/Giles Street in Toorak Gardens. The crashes occurred over five years (2017 to 2022), but no changes were made to the intersection during that time. Both directions of the non-priority road through the intersection are controlled by stop signs (one stop sign for vehicles heading south on George Street and two for vehicles heading north on Giles Street). Interestingly, none of the drivers on the non-priority road in the three crashes went straight into the intersection, suggesting that they were all aware that they were not on the priority road. One driver was heading south on George Street and intending to turn right to travel west on Kensington Road. The driver did not stop for the stop sign (unknown if he looked for traffic) but continued at a slow speed into the intersection and the path of a vehicle heading east on Kensington Road. Another driver was heading north on Giles Street and intending to continue straight through the intersection onto George Street. The driver stopped at the stop sign; however, he was distracted by events in his life and drove into the intersection without noticing the other car heading west on Kensington Road. The driver admitted that he was not focussed on driving but could not remember whether he looked for traffic or not. The final driver was also heading north on Giles Street and intending to continue straight through the intersection. The driver stopped and looked in both directions. Traffic was built-

up in the nearest lanes of Kensington Road. She edged through a gap in the traffic, looked again for traffic in the far lanes, but failed to see the car heading east on Kensington Road and continued into its path. The speed limit for Kensington Road is 60 km/h and for George Street/Giles Street it is 40 km/h. The highest level of injury in two crashes was hospital treatment and in the other it was hospital admission.

3.3.2. Crash history of locations

It is interesting to examine the number of right-angle crashes that have previously occurred at the intersections involved in this research. This provides an indication of how commonly such crashes are occurring at these locations. Police-reported crash data in SA (from the Traffic Accident Reporting System) were examined for right-angle crashes that occurred at the various intersections during a 10-year period prior to the occurrence of the crash that was investigated by CASR. As discussed in Section 3.3.1, five intersections had multiple crashes investigated at them at different dates (which meant that the number of crashes that occurred at the same intersection would differ for different crashes due to the preceding 10-year periods being slightly different). The average crash history (average number of crashes) was calculated for these intersections. The results are broken down in Table 3.5. Small numbers of crashes occurred at most intersections, with 33 having 10 crashes or less over 10 years (one crash or less per year). However, there were a few intersections that had large numbers of crashes occur at them, with 10 having 20 crashes or more across 10 years (two or more crashes per year). The mean number of crashes across the 50 intersections was 9.2 ($SD = 9.4$).

Table 3.5
Number of right-angle crashes that occurred over a ten-year period at intersections included in this research

Number of crashes	Number of intersections ($N = 50$)
31 to 35	2
26 to 30	1
21 to 25	6
16 to 20	4
11 to 15	4
6 to 10	8
1 to 5	17
0	8

Table 3.6 identifies the specific locations of the intersections at which 20 or more right-angle crashes occurred over the 10 years. Interestingly, seven of these intersections are in suburban areas (Toorak Gardens, Firle, Glanville, Morphett Vale, Millswood, Kilkenny, and Urrbrae), and the large number of crashes would likely be due to exposure (large volume of traffic). Two intersections (Angle Vale and Penfield) are in the Angle Vale, Virginia, and Two Wells area, which is the peri-urban grid system discussed in Section 3.3. The other intersection is a notorious ‘seagull’ intersection (see Section 3.3.3 for a description of ‘seagull’ intersections) between the Princes Highway and the Copper Coast Highway just north of Port Wakefield, which had been the site of several upgrades to improve safety over recent years (including advanced warning give way ahead signs that were bordered by yellow/orange, had ‘prepare to give way’ written on them, and had active flashing lights). Crashes continued to occur at this intersection, and it has since undergone a major redesign as a grade-separated junction at which the terminating road overpasses the through road (for road users turning

right onto the through road). This overpasses effectively eliminates the conflict point of the T-junction.

Table 3.6
Specific intersections at which 20 or more right-angle crash occurred over a ten-year period

Number of crashes	Specific intersection locations
35	Kensington Road and George Street/Giles Street, Toorak Gardens
32	Glynburn Road and Shelley Street, Firlie
30	Curtis Road and Heaslip Road, Angle Vale
24	Womma Road and Andrews Road, Penfield
23	Hart Street and Carlisle Street, Glanville
22	Main South Road and Hillier Road, Morphett Vale
21	Goodwood Road and Mitchell Street, Millswood Regency Road and Humphries Terrace, Kilkenny Cross Road and Waite Road, Urrbrae
20	Princes Highway and Copper Coast Highway, Port Wakefield

3.3.3. Difficult T-junctions and seagull intersections

Several T-intersections in this research, and the crashes investigated at them, are worthy of further mention as their design and layout are particularly difficult or complex for the driver on the terminating road (required to give way) to negotiate. Firstly, a crash occurred at the intersection of Bull Creek and Paris Creek Roads in the rural area or Paris Creek. Figure 3.11 shows the intersection layout. A car was turning right from Paris Creek Road to travel north on Bull Creek Road. The driver had stopped for the stop sign and was looking left and right for approaching traffic; however, it was particularly difficult to look for traffic approaching from the left due to the acute angle of Bull Creek Road leading into the intersection (driver required to look backwards rather than just to the left). Bull Creek Road also comes up a steep incline from a low gradient and around an embankment from that direction which restricts vision of fast-moving vehicles on this road (80 km/h speed limit). Figure 3.12 shows the view to the left from the driver's perspective (to check for traffic travelling north on Bull Creek Road). The driver was slowly moving out to get a better view and was prioritising the need to check for traffic from the left as it was so difficult to see but failed to adequately check for traffic from the right and moved into the path of a motorcycle travelling south on Bull Creek Road. The rider was admitted to hospital due to colliding with the car, being ejected from the motorcycle, and hitting the road. The car driver reported travelling through the intersection regularly and noted how difficult it is to navigate due to the restricted vision.

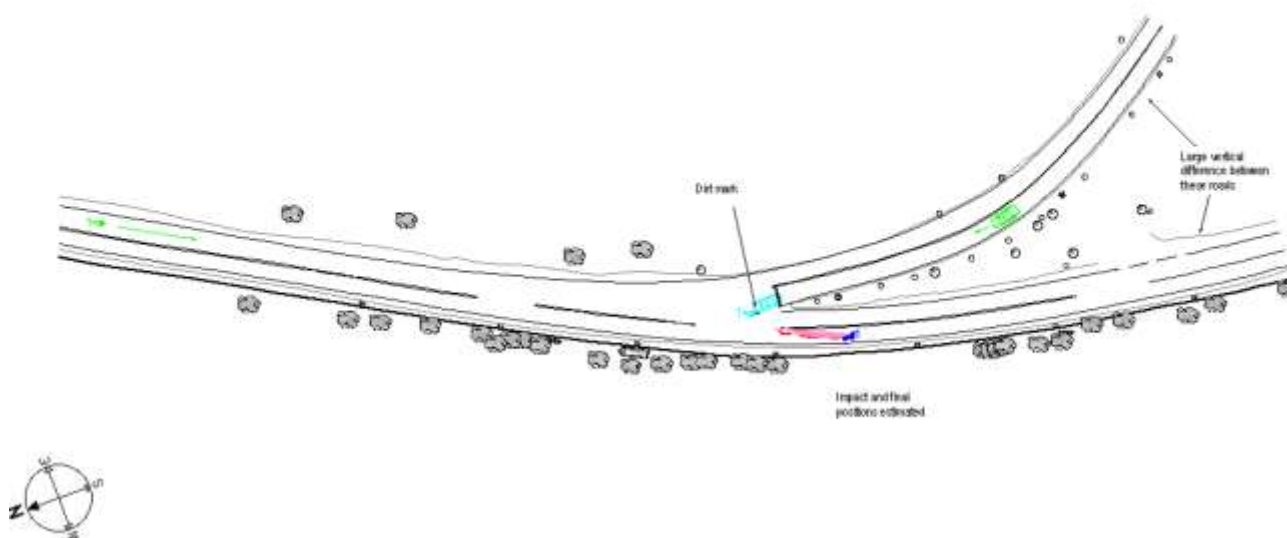


Figure 3.11

Site diagram of a fail to give way crash that occurred between a car and a motorcycle at the intersection of Bull Creek and Paris Creek Roads, Paris Creek



Figure 3.12

View of traffic travelling north on Bull Creek Road from the perspective of a road user at the stop sign at the termination of Paris Creek Road

A similar crash occurred at the intersection of Main and Red Roads in Hawthorndene. A vehicle was travelling east on Red Road and was intending to turn right onto Main Road to travel south. The

driver stopped at the give way sign where Red Road terminates and was looking for traffic. However, visibility was very poor in both directions due to the acute angle of Main Road to the left of Red Road and trees and embankments in both directions (Figures 3.13, 3.14 and 3.15). Also Red Road terminates at the bottom of a steep decline and traffic is busy on Main Road. The driver was concentrating so much on checking for traffic from the left and right that they failed to recognise a vehicle directly in front of them in the middle of the intersection that was turning right from Main Road to travel west on Red Road. Both vehicles turned at the same time. They were travelling slowly (60 km/h speed limit; both vehicles turning), so the collision was minor and only one vehicle occupant (an infant) required a precautionary check-up at the hospital. The driver on Red Road was very familiar with the intersection and noted how difficult it is to negotiate.

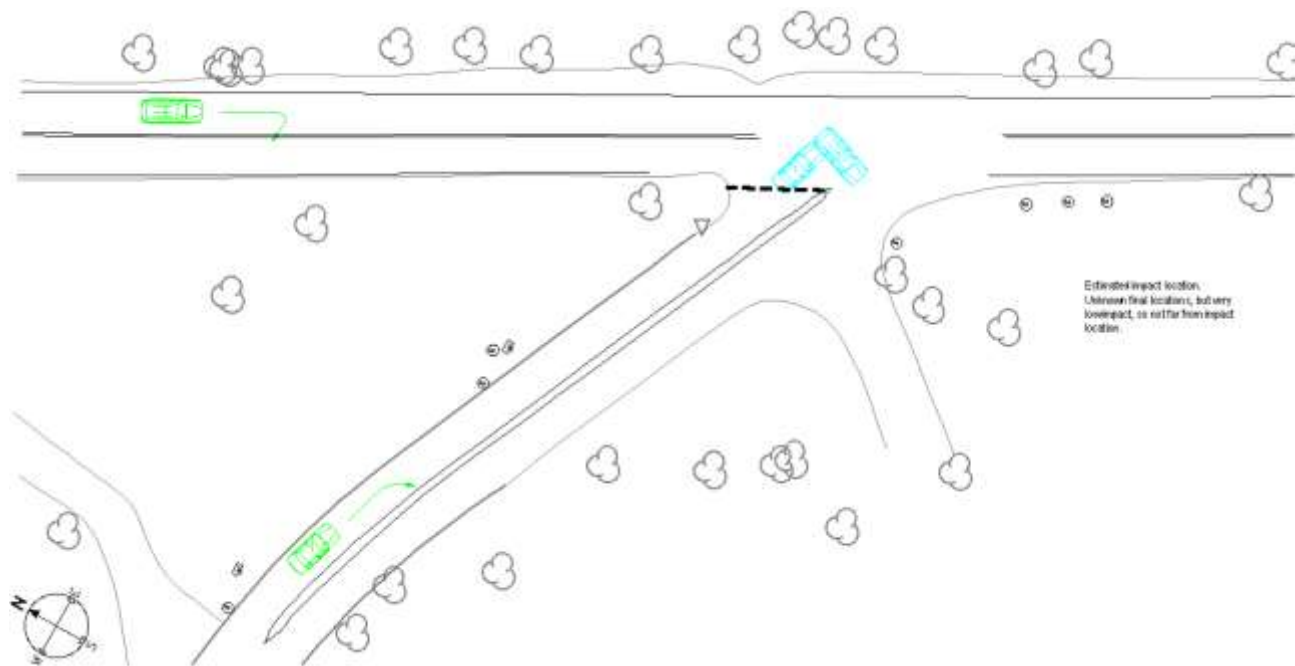


Figure 3.13

Site diagram of a fail to give way crash that occurred between two cars at the intersection of Main and Red Roads, Hawthorndene



Figure 3.14

View right from the perspective of a road user at the give way sign at the termination of Red Road



Figure 3.15

View left from the perspective of a road user at the give way sign at the termination of Red Road

Five fail to give way crashes occurred at ‘seagull’ intersections. In such intersections, a driver on the terminating road intending to turn right is required to slow or stop at the intersection and then, initially, look to the right for approaching traffic. Once the lane(s) to the right is clear, the driver continues into a slip/waiting lane located in the wide centre median. The driver then checks for traffic approaching from the left and, when it is clear, merges into the lane(s). As such, traversing a seagull intersection is a two-stage process (giving way first to the right, then the left) rather than

giving way to both directions at once and is intended to reduce the complexity and cognitive demands of the manoeuvre. However, in practice, seagull intersections increase the complexity of decision making and the manoeuvre for the right turning driver and this distraction can take their attention away from giving way to traffic (Harper, Smart, De Roos, & Harper, 2011; Turner, Tate, & Wood, 2019). Three crashes occurred at semi-seagull intersections and two occurred at full seagull intersections. At semi-seagull intersections the only slip/waiting lane through the median is for vehicles turning right from the terminating road and the median prevents vehicles turning right from the through road onto the terminating road (Figure 3.16). At full seagull intersections, there is an additional slip/waiting lane through the median for vehicles turning right from the through road onto the terminating road, which further increases the complexity of the intersection (Figure 3.17).

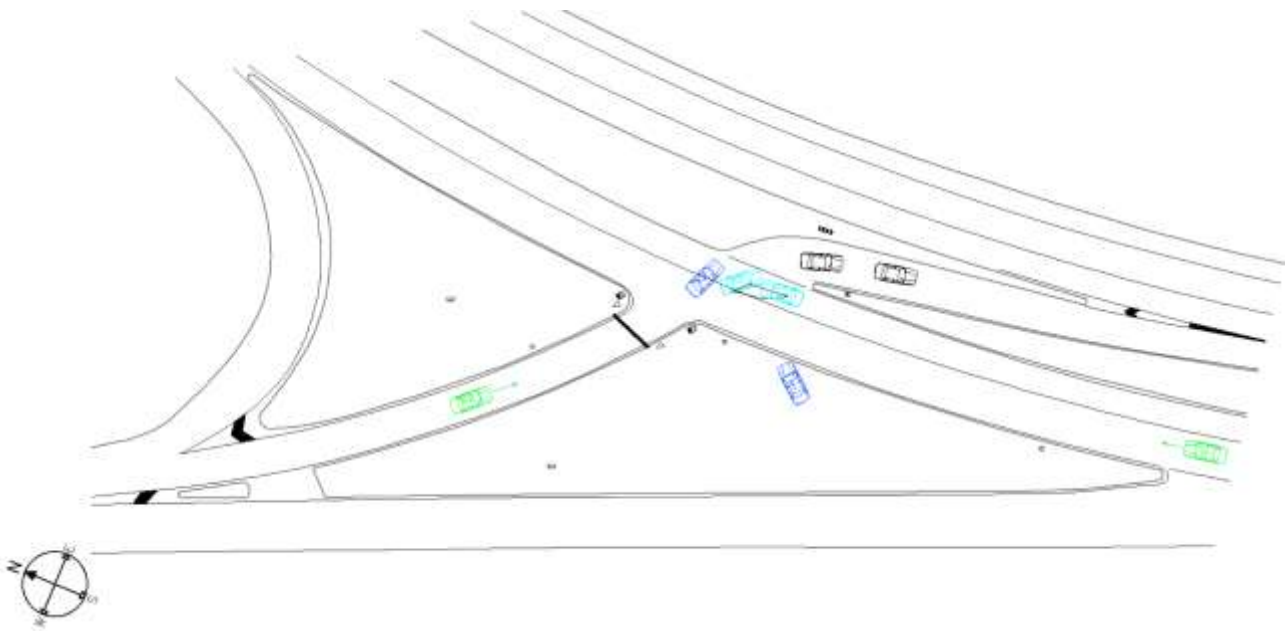


Figure 3.16
Site diagram of a fail to give way crash that occurred at a semi-seagull intersection

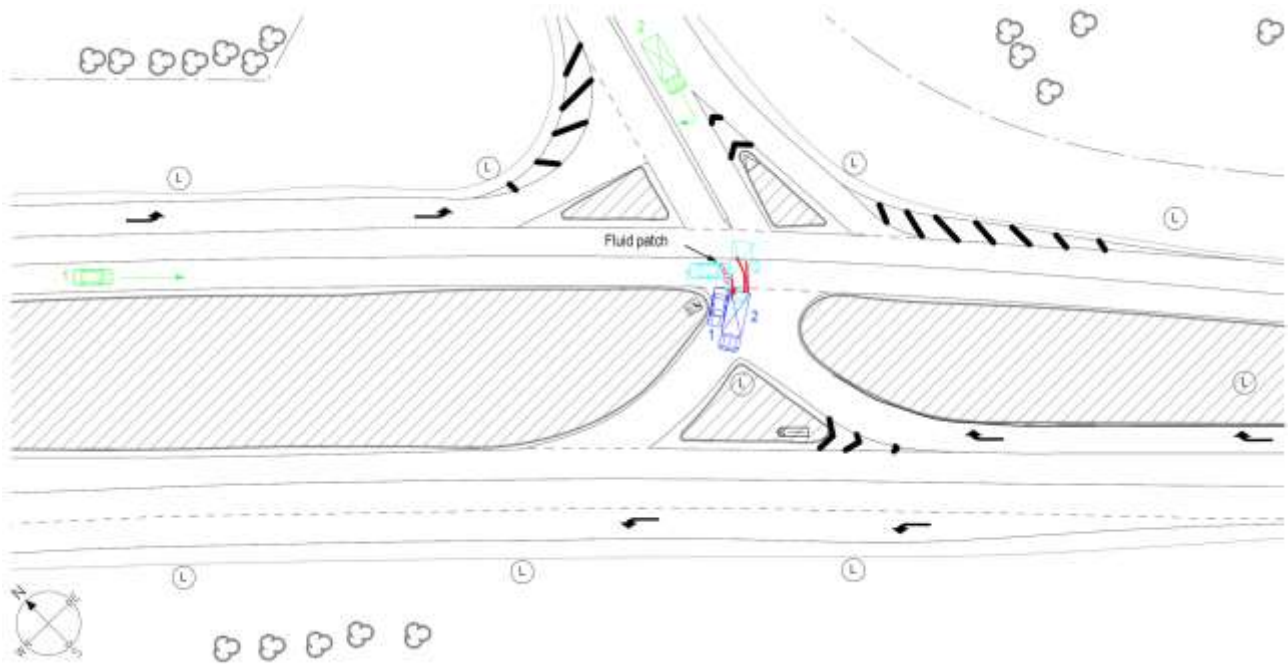
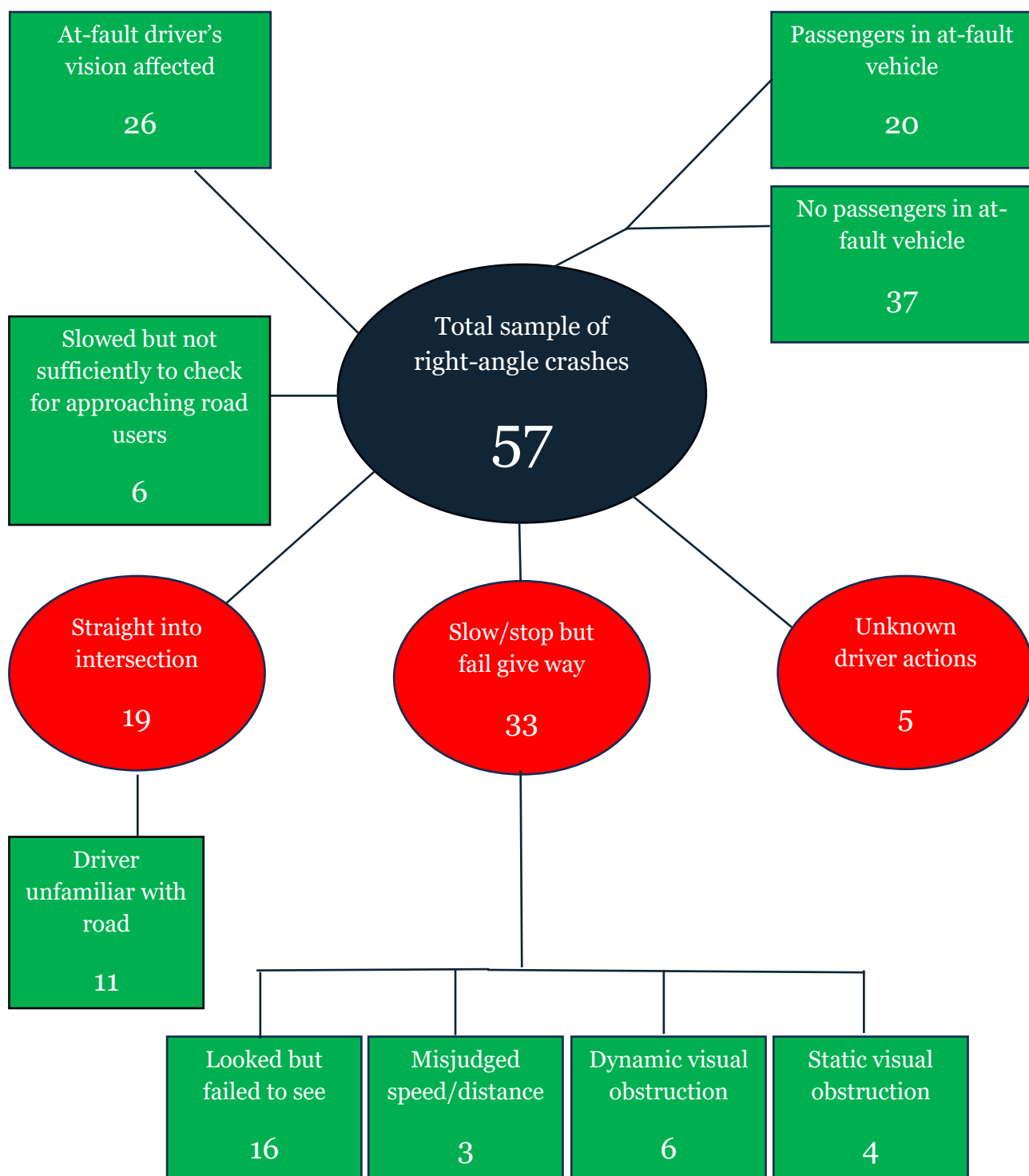


Figure 3.17
Site diagram of a fail to give way crash that occurred at a full seagull intersection

The additional complexity of seagull intersections can cause crashes when the driver turning from the terminating road becomes confused by the extra lanes (normal lanes plus slip/waiting lanes) and still check for traffic to the left at first when it is not necessary while not adequately checking for traffic from the right. They may neglect to give way to a vehicle turning right off the through road onto the terminating road and turn into them. The slip/waiting lane to turn right can also become full of vehicles waiting to turn right and the driver may attempt to continue into the slip/waiting but become stranded in the middle of the lane(s) of traffic approaching from their right (for a full discussion of the many ways in which the design of seagull intersections can lead to crashes see Turner et al. (2019)). This later error was made in one of the crashes investigated by CASR (Figure 3.16). In the other crashes, one driver's view of a vehicle approaching from the right was blocked by left turning vehicles, two drivers looked for traffic but failed to recognise approaching vehicles that were difficult to see due to their colour, and the details of what led the driver in the final crash to pull across the path of a truck approaching from the right are unknown (e.g., whether the driver looked for traffic).

3.4. Summary

The key results from this investigation into right-angle crashes at stop and give way sign-controlled intersections are summarised in Figure 3.18.



4. Possible treatments to improve safety at stop and give way sign-controlled intersections

As discussed in the previous section of this report, there are numerous factors that can contribute to a crash at a stop or give way sign-controlled intersection. Some factors can be attributed to those involved in the crash, such as a driver's unfamiliarity with the intersection. Others can be attributed to the road environment itself, such as a lack of appropriate signage or an intersection layout that provides poor visibility along the intersecting road. Here, discussion is presented about the possible treatments that can be used to improve safety at stop and give way sign-controlled intersections.

Ideally, intersections should be designed in such a way that they do not allow crash forces to exceed the human biomechanical tolerance to harm. In other words, they should not allow crash participants to be fatally or seriously injured in the event of a crash. Such designs conform to the philosophy of a Safe System. There are many reasons why this may not occur: existing constraints at the intersection (e.g., poor intersection geometry), budgetary constraints or a lack of justification for making improvements (e.g., treatment provides too low a benefit-cost ratio for consideration), and political hesitation to implement change (e.g., hesitation in reducing the speed limit), to name a few. It should also be noted that conforming to relevant design guidance and standards (e.g., O'Callaghan, Bekavac, & Mak, 2023; Standards Australia, 2022) does not ensure conformity with the Safe System – the design domain set out within these documents is made with consideration of safety but does not necessarily ensure an operating environment where fatal and serious injury crashes are eliminated. Upgrades or design changes to an intersection should use Safe System standards as the primary design preference and, where this is not possible, other safety improvements which provide some level of reduction in the risk of fatal and serious injury crashes should be sought. Essentially, a hierarchical approach should be implemented, prioritising the adherence to Safe System principles. In cases where compromises become necessary, the subsequent practical solution should be chosen based on the grounds of gaining the greatest improvement to safety. Turner, Jurewicz, Pratt, Corben, and Woolley (2016) and Woolley, Stokes, Turner, and Jurewicz (2018) both provide suitable hierarchies.

4.1. Understanding the safety problems

Before selecting safety treatments, it is important to match potential treatments with the actual safety problems that exist. This will help to ensure that the safety problems will be adequately addressed. Useful information for how to understand the safety problem and perform preliminary investigations into the suitability of a design can be found in Appendix A.

4.2. Safe System aligned treatments

Treatments well aligned to the Safe System are those that minimise and potentially eliminate the risk of fatal and serious injuries. These treatments should be considered in preference to less well aligned treatments. There are reasons why Safe System aligned treatments may not be appropriate and these reasons should be documented to understand why they were not chosen and why a lesser design prevailed. Often, the high cost associated with some treatments plays a significant role in their exclusion, especially for intersections where the traffic volume does not warrant such high levels of

investment. Other considerations, such as the need to optimise traffic flow, may also influence the selection of less well-aligned treatments.

Safe System aligned treatments should be aimed at minimising or eliminating the risk of fatal and serious injuries for all road users using the intersection. They achieve this objective through several means: by reducing the speeds of vehicles as they traverse the intersection, by reducing the angle of impact between vehicles in the event of a collision, or by eliminating conflicting movements between road users. While some treatments may be useful for minimising the risk of fatal and serious injuries for some road users, they may not offer the same benefits to others. For instance, multi-lane roundabouts can substantially reduce harm caused in multiple vehicle crashes but may not lessen the risk of harm to cyclists.

A list of Safe System aligned treatments is presented in Tables 4.1, 4.2 and 4.3. These treatments are presented in no particular order. Some treatments, such as a raised platform intersection, may only require retrofitting to the existing intersection layout. Other more intensive treatments, such as grade separation or installation of a roundabout, require a complete redesign of the intersection.

Table 4.1

Treatments for mitigating harm at stop and give way sign-controlled intersections that are well aligned to the Safe System

Treatment	Application	Function	Crash mechanisms*	Notes
Grade separation	High volume intersections Rural and metro	Elimination of conflicts	May eliminate harm from fail to give way and run-through crashes	Very high cost Reliant on separation of all intersecting traffic streams. Remaining intersections of traffic streams pose potential for harm if not treated appropriately
Roundabout (multi-lane)	High volume intersections Metro	Reduction of speed Reduction of impact angle Simplify give way decision making	May mitigate harm from fail to give way and run-through crashes	Reliant on appropriate speed reduction through intersection. Cyclists should not enter the roundabout – separate from vehicular traffic stream on approach
Roundabout (single-lane)	Low-medium volume intersections Metro	Reduction of speed Reduction of impact angle Simplify give way decision making	May mitigate harm from fail to give way and run-through crashes	May present a hazard to pedestrians and cyclists

*Fail to give way = crashes where the minor road driver stops or slows their vehicle but fails to recognise and pulls out in front of an oncoming vehicle; Run-through = crashes where the vehicle runs through the intersection at speed because the driver fails to recognise either the need to give way or the presence of the intersection.

Table 4.2

Treatments for mitigating harm at stop and give way sign-controlled intersections that are well aligned to the Safe System
(continued)

Treatment	Application	Function	Crash mechanisms*	Notes
Rural roundabout	Low-medium volume intersections High speed roads	Reduction of speed Reduction of impact angle Simplify give way decision making	May mitigate harm from fail to give way and run-through crashes	May require substantial land acquisition. May present a hazard to pedestrians and cyclists
Compact rural roundabout	Low-medium volume intersections High speed roads	Reduction of speed Reduction of impact angle Simplify give way decision making	May mitigate harm from fail to give way and run-through crashes	Few examples built to date – potential issues may yet to be identified
Raised platform intersection	Low-medium volume intersections Metro (potential for rural)	Reduction of speed	May mitigate harm from fail to give way and run-through crashes	Requires steep enough ramp angle to produce adequate reduction in speed through intersection Application to rural high speed roads remain untested
Raised plateau	Low-medium volume intersections Metro and rural	Reduction of speed	May mitigate harm from fail to give way and run-through crashes	Can be used in conjunction with other treatments (e.g., speed reduction on approach to compact rural roundabout) Few examples built to date – potential issues may yet to be identified
Close/remove intersection	All intersections Metro and rural	Elimination of conflicts	May eliminate harm from fail to give way and run-through crashes	Requires traffic to use another intersection – problem is moved to new location rather than being resolved if other intersection is not of a higher safety standard
Left-in/left-out, ban right turns	Low-medium volume intersections Metro and rural	Reduction of impact angle Elimination of conflicts	May mitigate harm from fail to give way and run-through crashes	Reliant on appropriate control of remaining movements (e.g., use of left turn acceleration lanes on high speed roads) Requires adequate U-turn facilities in-place of right turns

*Fail to give way = crashes where the minor road driver stops or slows their vehicle but fails to recognise and pulls out in front of an oncoming vehicle; Run-through = crashes where the vehicle runs through the intersection at speed because the driver fails to recognise either the need to give way or the presence of the intersection.

Table 4.3

Treatments for mitigating harm at stop and give way sign-controlled intersections that are well aligned to the Safe System
(continued)

Treatment	Application	Function	Crash mechanisms*	Notes
Low speed environment	Low-medium volume intersections Metro and rural	Reduction of speed	May mitigate harm from fail to give way and run-through crashes	Requires appropriate reinforcement of speed reduction

*Fail to give way = crashes where the minor road driver stops or slows their vehicle but fails to recognise and pulls out in front of an oncoming vehicle; Run-through = crashes where the vehicle runs through the intersection at speed because the driver fails to recognise either the need to give way or the presence of the intersection.

4.3. Other treatments

Other treatments are those that offer a reduction in the risk of fatal and serious injuries but are unlikely to completely eliminate this risk. Additionally, these treatments may also effectively address some types of crashes but not others. For instance, reinforced signage on a minor road may reduce run-through crashes but may have limited impact on situations where a driver slowed or stopped but failed to give way to traffic on the major road. Many of these treatments function by reducing the likelihood of crashes but do little or nothing to reduce their severity should a crash occur.

A list of safety treatments less well aligned to the Safe System is presented in Tables 4.4, 4.5 and 4.6. These treatments are presented in no particular order. Many of the treatments listed require minimal redesign of the intersection, resulting in reduced financial and time investment, which makes them appealing for low-volume intersections or other intersections where a larger investment may not be justifiable.

Table 4.4

Treatments for mitigating harm at stop and give way sign-controlled intersections that are less well aligned to the Safe System

Treatment	Application	Function	Crash mechanisms*	Notes
Rural junction active warning system (RJAWS)	Low-medium volume intersections Rural high speed roads	Reduction of speed	May mitigate harm from fail to give way crashes	Reliant on conformity to reduced speed limit over short distances Effectiveness dependent on types of movements that are detected and therefore trigger reduced speed limit
RJAWS Lite	Low-medium volume intersections Rural high speed roads	Reduction of speed	May mitigate harm from fail to give way crashes	Reduction in speed not as great as RJAWS – offset by lower cost

*Fail to give way = crashes where the minor road driver stop or slows their vehicle but fails to recognise and pulls out in front of an oncoming vehicle; Run-through = crashes where the vehicle runs through the intersection at speed because the driver fails to recognise either the need to give way or the presence of the intersection.

Table 4.5
Treatments for mitigating harm at stop and give way sign-controlled intersections that are less well aligned to the Safe System (continued)

Treatment	Application	Function	Crash mechanisms*	Notes
Reinforced control signage/ advanced warning signage	Low-medium volume intersections Metro and rural	Reduction of crash likelihood (increased awareness of control)	May mitigate harm from run-through crashes	Run-through events have been observed to continue at intersections where this has been implemented Unlikely to affect fail to give way crashes
Activated minor road signage	Low-medium volume intersections Rural	Reduction of crash likelihood (increased awareness of control)	May mitigate harm from run-through crashes	Unlikely to affect fail to give way crashes
Teardrop median	Low-medium volume intersections Rural	Reduction of crash likelihood (increased awareness of intersection)	May mitigate harm from run-through crashes	Unlikely to affect fail to give way crashes
Staggered T-junction	Low-medium volume intersections Rural	Reduction of crash likelihood (reduced conflict points, increased awareness of intersection)	May mitigate harm from fail to give way and run-through crashes	Expensive due to land acquisition Less effective at reducing fatal and serious injury crashes than previously estimated
Turning lanes	All intersections Metro and rural	Reduction of crash likelihood (reduced likelihood of rear end/side swipe crashes)	May mitigate harm from fail to give way crashes	May have added benefit of reducing "pressure" placed on those turning at an intersection by through traffic queuing behind, leading to less risky manoeuvres being undertaken
Increasing intersection conspicuity	All intersections Metro and rural	Reduction of crash likelihood (increased awareness of intersection presence)	May mitigate harm from run-through crashes	May have added benefit of increasing general awareness of the intersection, leading to greater care being taken when traversing the intersection

*Fail to give way = crashes where the minor road driver stops or slows their vehicle but fails to recognise and pulls out in front of an oncoming vehicle; Run-through = crashes where the vehicle runs through the intersection at speed because the driver fails to recognise either the need to give way or the presence of the intersection.

Table 4.6
Treatments for mitigating harm at stop and give way sign-controlled intersections that are less well aligned to the Safe System (continued)

Treatment	Application	Function	Crash mechanisms*	Notes
Increased lighting	All intersections Metro and rural	Reduction of crash likelihood (increased awareness of intersection presence)	May mitigate harm from fail to give way and run-through crashes	Only beneficial when dark Likely to also benefit vulnerable road user safety by increasing their visibility at the intersection
Traffic signals	Med-high volume intersections Metro	Reduction of crash likelihood (increased control)	May mitigate harm from fail to give way and run-through crashes	Reduces the risk of crashes by increasing control on road users but does nothing to reduce the severity of crashes when they occur
Rumble strips	Low-med volume intersections Rural	Reduction of crash likelihood (increased awareness of intersection presence)	May mitigate harm from run-through crashes	Unlikely to affect fail to give way crashes

*Fail to give way = crashes where the minor road driver stops or slows their vehicle but fails to recognise and pulls out in front of an oncoming vehicle; Run-through = crashes where the vehicle runs through the intersection at speed because the driver fails to recognise either the need to give way or the presence of the intersection.

5. Discussion

The purpose of this report was to provide an insight into right-angle crashes at stop and give way sign-controlled T-junctions and crossroad intersections, and to understand the preceding driver behaviour and circumstances that lead to these crashes. It was found that the at-fault drivers in these crashes did not differ from at-fault drivers in other types of crashes in their likelihood of testing positive for the presence of alcohol or drugs in their system, or of having passengers present in their vehicles at the time of the crash. This suggests that these crashes were not more likely than other crashes to result from risky driver behaviour such as driving while under the influence or distracted but, rather, that they mostly resulted from driver error and external factors. This latter conclusion is based on the following findings:

- In 33 crashes, the at-fault driver slowed or stopped at the intersection before moving into the path of another road user on the priority road, suggesting that they were aware of the intersection and their requirement to give way but another factor contributed to the crash (16 looked but failed to see the other road user, while for 13 their vision was either blocked by dynamic or static obstructions or they saw the other road user but misjudged the speed, distance, or gap in traffic).
- In 19 of the crashes, the at-fault driver proceeded straight into the intersection without slowing or stopping, which suggests that they thought they were on the priority road and were completely unaware of their requirement to give way, or unaware that they were approaching an intersection.
- The most common preceding circumstance of the at-fault drivers in run-through crashes was that they were unfamiliar with the road.
- There were visibility issues in 46% of the crashes that affected the at-fault driver's vision of approaching road users.

These findings are discussed further in this section of the report. Firstly, it is interesting to note that other studies have reported similar proportions of right-angle crashes according to the type of error that the at-fault driver made. Preston and Storm (2003) reported that the majority (57%) of right-angle crashes at stop sign-controlled crossroad intersections involve a vehicle stopping at the stop sign before entering the intersection, and that a smaller proportion (26%) involve a vehicle travelling straight through. Similarly, Retting, Weinstein, and Solomon (2003) examined crashes that occurred at stop sign-controlled intersections across four US cities and found that 78% were due to non-compliance of the stop sign. Of these, 63% involved a vehicle stopping before entering the intersection and 24% involved a vehicle that failed to stop at the stop sign. More recent research by Stokes and Woolley (2022) has reinforced that the predominant driver error at unsignalised intersections is related to their awareness of other traffic on the priority/through road, which is often referred to as a 'looked-but-failed-to-see' error. In 'looked-but-failed-to-see' crashes, drivers look in the direction where the other road users are but do not perceive them (Koustanaï, Boloix, Van Elslande, & Bastien, 2008).

The present research showed that many of the drivers (13 of 33) who slowed or stopped at the sign and checked for traffic did not detect an approaching road user on the priority road (and moved into their path) due to visual obstructions that were either dynamic (e.g., vehicles on the priority road) or static (e.g., road signs), or did identify the approaching road user but misjudged the speed, distance, or available gap in traffic. However, 16 drivers did not detect an approaching road user when they were specifically checking for traffic in that direction and their vision was clear. Exactly what causes

this is unclear. The concept of ‘change blindness’ suggests that humans have a poor memory for the visual world and often fail to report, detect, or see changes in visual stimuli that are obvious once pointed out (Galpin, Underwood, & Crundall, 2009; Jensen, Yao, Street, & Simons, 2011; Martens, 2011; Simons & Levin, 1997; Simons and Rensink, 2005). Research on ‘change blindness’ (Galpin et al., 2009; Rensink, 2002; Rensink, O’Regan, & Clark, 1997; Simons & Rensink, 2005; Velichkovsky, Dornhoefer, Kopf, Helmert, & Joos, 2002) has shown that major change in the visual field can go unnoticed when it occurs during blink, blank or saccade. Certainly, the phenomenon of ‘inattention blindness’ may explain why drivers do not recognise smaller road users, such as motorcycle or bicycle riders (Berghoefer, Huemer, & Vollrath, 2023; Clabaux, Brenac, Perrin, Magnin, Canu, & Van Elslande, 2012; Herslund & Jørgensen, 2003), when they are specifically scanning for passenger vehicles (i.e., cars). ‘Inattention blindness’ is the failure to notice a highly visible, but unexpected, object that a person may be looking at directly when their attention is focussed on another task (in this case looking for a specific type and size of vehicle) (Jensen et al., 2011; Mack, 2003). However, in most (12 of 16) of the crashes examined in the present report, other passenger vehicles were not detected by the driver who looked for traffic but failed to give way. Both ‘change blindness’ and ‘inattention blindness’ are failures of visual awareness in which people fail to see something right in front of their eyes, and both may be involved in ‘looked-but-failed-to-see’ crashes (Jensen et al., 2011; White, 2006). The present research also demonstrated, however, that the ability to successfully identify another road user can be affected by external factors, such as visibility issues at the intersection. Other research has also shown that intersection factors, such as sight distance, skew angle, presence of horizontal or vertical curvature, presence of median, or lighting, contribute to failure to give way errors and intersection crashes (Burchett & Maze, 2006; Donell, Harwood, Bauer, Mason Jr, & Pietrucha, 2002; Harwood, Pietrucha, Wooldridge, Brydia, & Fitzpatrick, 1995). While external factors can be addressed, it is generally accepted that the human visual scanning task at uncontrolled intersections, and the mental processing involved, is so complex that recognition failures will continue to occur (Herslund & Jørgensen, 2003; Woolley et al., 2018).

In a minority of crashes (six) in the current study, the driver slowed and looked for approaching vehicles but did not slow to a speed that would be sufficiently low to safely check for traffic. Older research by Pietrucha, Opiela, Knoblauch, and Crigler (1989) conducted site observations at 142 stop sign-controlled intersections in four US states. Of the total 31,212 vehicle movements that were observed, 67% of drivers failed to come to a complete stop. This suggests that drivers may fail to slow to an appropriate speed or completely stop for a stop sign more commonly than the present study suggests (although it should be acknowledged that the Pietrucha et al. (1989) study was conducted more than 30 years again in the US, which may have less enforcement of drivers who disobey stop signs compared to the present Australian context). This driver behaviour may be common but it does not always result in a crash. Interestingly, even older observational research by Mounce (1981) at 66 low-volume, rural stop sign-controlled intersections in the US demonstrated a statistically significant relationship between increased traffic volume and decreased stop sign violation and increased minor road sight distance and increased stop sign violation. This suggests that drivers will regulate this behaviour in difficult traffic conditions but increase the behaviour if they believe the road conditions are more forgiving.

An interesting finding was that right-angle crashes at stop and give way sign-controlled intersections were more likely than other types of crashes to occur on roads with speed limits of 70, 80 and 90 km/h but less likely to occur on roads with speed limits of 100 and 110 km/h. Roads with speed limits of 70, 80 and 90 are often arterial and collector roads that intersect with many other roads (and, therefore, have many conflict points where right-angle crashes would be common). These roads

make up the peri-urban grid system mentioned in Section 3.3 of this report. In comparison, roads with speed limits of 100 and 110 km/h include freeways and motorways with controlled access (merge lanes and grade separated junctions rather than intersections) that prioritise free-flowing, high-speed traffic and, therefore, have few potential conflict points. The type of crashes that would be more common on freeways and motorways would be single vehicle loss-of-control crashes.

5.1. Improving safety at stop and give way sign-controlled intersections

Ideally, safety at stop and give way sign-controlled intersections can be improved through superior intersection design and countermeasures/treatments that act to either prevent crashes occurring or reduce the severity of injury when they do occur (e.g., through a reduction in crash forces). The present research identified that there are two distinct types of right-angle crashes that occur when drivers fail to obey stop or give way signs, and they have different driver actions and preceding behaviours that lead to them. Consequently, they also differ in the methods that can be used to address them. A specific countermeasure may be effective for one type but not for the other. Additionally, Chapter 4 of this report highlighted that there are many other factors that must be considered when designing or upgrading an intersection, such as the cost of potential treatments, their predicted effectiveness, and the ongoing optimisation of traffic flow.

Crashes in which a driver fails to recognise an approaching road user on an adjacent road despite checking for traffic in the appropriate directions ('looked-but-failed-to-see' crashes) are difficult to address. They can occur at all unsignalised intersections due to the reliance on judgement by the driver as to whether it is safe to traverse the intersection. As demonstrated in this report, many unsignalised intersections have pre-existing/external factors that contribute to the occurrence of such crashes, for example visibility issues (e.g., trees and embankments) and suboptimal intersection design (e.g., acute approach angles; location near top/bottom of hill; and 'seagull' intersections). As a result, the first step in efforts to prevent these crashes would be to address such pre-existing factors through a thorough assessment of the intersection and then re-designing or upgrading it based on an understanding of the nature of the specific safety problem at the intersection. The assessment process may include an examination of the crash history of the intersection, road safety audits and Safe System assessments, and stakeholder (e.g., local council) and community consultation. However, even when pre-existing factors are accounted for, recognition failure crashes may still occur.

A complete re-development or re-design of the intersection to eliminate potential conflicts, such as through grade separation of the roads in the junction (in which one road passes over or under the other), is effective at preventing 'looked-but-failed-to-see' crashes by removing the opportunity for this type of human error to occur. However, the installation of a grade separated junction is a very long and expensive process that is not practical for many intersections. Such redevelopments can be prioritised to specific intersections that, through detailed assessments, have been identified as having a particularly high safety problem (e.g., poor crash history, pre-existing difficulties related to design flaws or visibility issues, high traffic volume, etc.). Research has also shown that grade separation of intersections with heavily oversaturated traffic conditions leads to good benefit-cost ratios (He, Kamineni, & Zhang, 2016) related to improved traffic capacities and efficiencies. A specific example of the implementation of a grade separated junction at a T-junction with a history of safety issues related to its design and poor crash record (intersection between Princes Highway and the Copper Coast Highway just north of Port Wakefield) was briefly noted in Section 3.3.2.

The installation of traffic lights at intersections does not eliminate the conflict points (drivers may still disobey the lights and many signalised intersections allow drivers to make uncontrolled right turns across oncoming traffic) but does increase the level of control of the traffic situation. They are expensive to install, however, and require ongoing maintenance and a permanent power source, which makes them impractical for many intersections (particularly rural, low volume intersections). Roundabouts also provide increased control of the traffic situation, although still require drivers to check for traffic and decide when it is safe to enter the roundabout, and, therefore, 'looked-but-failed-to-see' crashes can still occur. They are also expensive, require extensive land acquisition, can increase the complexity of the traffic situation (e.g., through multiple lanes and exits), and can increase risk for bicyclists and pedestrians (Daniels, Nuyts, & Wets, 2008; Harkey & Carter, 2006; Poudel, & Singleton, 2021; Vignali, Pazzini, Ghasemi, Lantieri, Simone, & Dondi, 2020). The main benefits of roundabouts, however, is that they act to reduce vehicle speeds on all approaches into the intersection (they also reduce impact angle), which reduces the crash forces and, therefore, injury severity of any crashes (Hydén & Várhely, 2000; Isebrands, Hallmark, & Hawkins, 2014), and simplify the give way decision making process (the driver is only required to give way to traffic approaching from one direction – from the right in Australia). Indeed, if high levels of traffic control are not practical, then methods to reduce vehicle speeds are likely to be the best option. Ideally, to align with safe system principles, crash forces should be reduced to a level that does not exceed the human biomechanical tolerance to harm (Woolley et al., 2018). Other methods to reduce vehicle speed include raised platforms and plateaus, rural junction activated warning systems (Mongiardini, Stokes, & Woolley, 2022), and lower speed limits in the vicinity of the intersection (see Chapter 4). In addition to decreasing injury severity, reduced vehicle speeds also help to prevent crashes due to improvements in driver reaction time, braking distances, and vehicle control at slower speeds (Kloeden, Ponte, & McLean, 2001).

Crashes in which the at-fault driver proceeded straight into the intersection without slowing or stopping can also be eliminated through grade separated junctions or reduced through traffic lights and roundabouts (which increase visibility and awareness of the intersection), but the same practical considerations apply, and they will not be possible for all intersections. Methods to reduce vehicle speeds are also important to reduce the injury severity because it is possible in run-through crashes for both vehicles to be travelling at the speed limit when they collide. This research indicates that many run-through crashes occur because the at-fault driver is unfamiliar with the road and unaware of their requirement to give way, or even that they are approaching a crossroad intersection. It was also demonstrated that many run-through crashes occur in areas where the intersecting roads and roadside environments are similar in appearance, without visual cues (e.g., roadside buildings, businesses, houses, or infrastructure) that would assist drivers to differentiate between priority and non-priority roads. This suggests that efforts to prevent crashes at such intersections should focus on increasing driver awareness of the intersection and of their requirement to give way to other traffic. However, this research also shows that, even after such methods (including advanced warning signs, two stop or give way signs at the intersection, delineation, a tear-drop median, off-set junction of the non-priority road, etc.) have been implemented at crossroad intersections, run-through crashes still occur. Therefore, there is considerable scope for novel and innovative approaches to increase driver awareness.

One such novel method is to install transverse rumble strips on the approach of both sides of the non-priority road to the intersection. Rumble strips are a series of raised lines separated by approximately several metres from each other that run across the lane approaching the intersection. When a vehicle's tyres drive over these, they provide an audible rumbling, tactile vibration, and

visual (if marked) warning on the approach to the intersection to capture the driver's attention. Rumble strips are more common in the USA, and many studies from the USA have examined their safety benefits. Research by Thompson Burris and Carlson (2006) measured vehicle speeds along the approach to rural stop sign-controlled intersections before and after the installation of rumble strips. They found that the installation of rumble strips produced small but statistically significant reductions in approach speeds (around 1 mile per hour or less). Research from the Virginia Department of Transportation (1983) found that rumble strips led to a 37% reduction in total crash frequency and a 93% reduction in fatal crashes for stop sign-controlled intersections. The crash rate for rear-end and ran-stop-sign crashes was reduced by 89% (Staplin, Lococo, & Byington, 1998). More recent research by Srinivasan, Baek, and Council (2010) examined data from 20 stop sign-controlled intersections in Minnesota and 134 stop sign-controlled intersections in Iowa before and after the installation of rumble strips to determine their safety effectiveness. They found a 21% reduction in fatal, incapacitating injury, and non-incapacitating injury crashes and a 39% reduction in fatal and incapacitating injury crashes respectively. The Minnesota Department of Transportation (Harder, Bloomfield, & Chihak, 2001) examined driver stopping performances in a driving simulator and found that rumble strips cause drivers to use their brakes more and to apply them earlier. Research in Texas by Miles, Pratt, and Carlson (2006) studied rumble strips installed at two rural stop sign-controlled intersections and observed no sudden braking or swerving manoeuvres at the sites. Rumble strips are not commonly in use in SA, although they are present at a small number of intersections.

Other innovative efforts attempt to increase the effectiveness of advanced warning signage and/or signage at the intersection by making the signs bigger and more visible, for example, an arch-type overhead sign that has flashing lights. However, these are subject to practical restraints, such as the cost to install and the power source requirements. Srinivasan (2008) studied crashes at stop sign-controlled intersections in North and South Carolina, USA before and after the installation of overhead flashing beacons. They found a 12% reduction in angle crashes. Similarly, Murphy and Hammer (2007) also conducted a before and after evaluation of overhead flashing beacons at four-leg, two-way stop sign-controlled intersections in North Carolina and found a 12% decrease in total crashes, a 9% decrease in injury crashes, a 40% decrease in severe injury crashes, and a 26% reduction in 'ran stop-sign' crashes. Other before and after evaluations of overhead flashing beacons in the USA have also demonstrated crash reductions (Brewer and Fitzpatrick, 2004; Stackhouse & Cassidy, 1996). Research by Pant, Park, Neti, and Hossain (2007) in Ohio found that overhead flashing beacons led to reduced vehicle speeds in the major directions of traffic at rural stop sign-controlled intersections, particularly at intersections with inadequate stopping sight distance. However, the beacons had little effect on accepted or rejected gaps and were ineffective in reducing stop sign violations. They also found no statistically significant reduction in crashes. Figure 5.1 shows an example of an overhead warning sign in use currently on Brookman Road in Meadows SA. However, such overhead signs are not commonly in use in SA.



Figure 5.1

Overhead warning sign on Brookman Road, Meadows, South Australia

It should be acknowledged, however, that no matter what warnings or treatments are implemented at crossroad intersections to increase awareness, there are a subgroup of drivers who, given certain circumstances (particularly if they are unfamiliar with the road), will drive straight into the intersection. The only way to ensure that such crashes do not occur is to grade separate the junction to eliminate the conflict, but as already mentioned, this can be cost prohibitive. Another novel approach is to off-set the path of the non-priority road by some distance (e.g., 50 metres or more), which effectively creates two T-junctions, so that the non-priority driver must turn right, travel for some distance and then turn left to continue on the non-priority road. However, this report has demonstrated that T-junctions have their own safety complications (i.e., 'looked-but-failed-to-see' crashes), and the installation of such an off-set intersection would be expensive and require considerable land acquisition in many cases.

Vehicle technology can also assist in the prevention of crashes in which drivers fail to obey stop or give way signs. New generations of vehicles have increasingly advanced GPS-based mapping and navigational systems. These systems now identify intersections controlled by stop or give way signs and warn the driver when they are approaching them (as they do with speed detection cameras). This technology will become more prevalent as the general vehicle fleet is updated and it will increase driver awareness of these signs. The technology could also be improved to detect the speeds on the approach to the signs, and potentially provide more intrusive (e.g., louder) warnings where required. Active technology could also be developed to automatically stop or slow the vehicle based on speed and distance calculations (similar to the technology used for Autonomous Emergency Braking).

Forward facing vehicle cameras also have the ability to detect signs on the approach to the intersection and could warn the driver or intervene to slow or stop the vehicle. Additionally, newer vehicles provide better occupant protection in the event of a crash through airbags, crumple zones, etc. that help to reduce injury severity (Anderson & Doecke, 2010; Anderson & Hutchinson, 2010; Newstead, Watson, & Cameron, 2008; Ryb, Dischinger, & Ho, 2009). It should also be noted that vehicles capable of autonomous driving would not make many of the types of human errors that lead to right angle crashes (e.g., driving straight through an unfamiliar cross-road intersection), although some errors would still be possible (e.g., the autonomous vehicle had slowed or stopped at the intersection but could not detect an approaching road user because its vision of them was blocked).

5.2. Study limitations

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). Attempts are also made to collect an equal portion of metropolitan cases to rural cases by scheduling double the number of 'rural only' shifts compared to 'all crashes' shifts. As such, they are not representative of all casualty crashes in South Australia. Crashes in remote areas (further than 100 km from Adelaide CBD) are not investigated and, therefore, would not be represented in the present crash sample. Crashes outside of shift times (specifically during late night and early morning hours) are investigated only if they were attended by the Major Crash Investigation Unit of the South Australian Police and, therefore, would be underrepresented and those that are in the database would have a bias towards high severity. Also, for a crash to be investigated, at least one participant must be transported to hospital by ambulance. Consequently, minor injury and property damage-only crashes were not represented in this study. Given, however, that the aim of the Safe System is to prevent serious and fatal crashes, the absence of low severity crashes in the sample does not threaten the validity of the results of the study.

5.3. Future research

Observational research at stop and give way sign-controlled T-junctions and crossroad intersections would be beneficial to examine actual driver behaviour at these locations. Specifically, it would quantify the extent to which drivers continue straight into the intersection or do not slow sufficiently for the sign to allow them to safely check for traffic. While most instances of these driver actions would not result in a crash, this would only be due to circumstance (i.e., the absence, or position, of another vehicle on the intersecting road). Each instance would have the potential to lead to a crash and it would, therefore, be useful to quantify the frequency of these actions. This could be conducted through researchers physically attending a sample of intersections and recording data or through the installation of video cameras at the locations. Depending on costs, the latter method would allow for more data to be collected (through constant video recording at potentially many intersections). Computer algorithms can be used to reduce the time required to process the video data (e.g., using artificial intelligence to identify when a vehicle is traversing the intersection from the minor road). The frequency could be compared between different intersections (e.g., different designs, different safety treatments, advanced warning signs versus no advanced signs, etc.) to identify the factors that correlate with the lowest rate of occurrence. It would also be useful to install speed measuring devices (e.g., pneumatic tubes) on the approach to stop and give way signs to examine vehicles speeds. Again, average speeds could be compared between different intersections (e.g., those with rumble strips versus those without, advanced warning signs versus no advanced signs, etc.) and may identify the

factors that are effective at increasing driver awareness of the intersection and requirement to give way or encouraging them to sufficiently slow their approach speed.

5.4. Conclusion

This report has demonstrated that one of the most common types of crashes that occur on the road network – right-angle crashes at stop and give way sign-controlled T-junctions and crossroad intersections – largely results from driver error (e.g., looked-but-failed-to-see errors) and external factors (i.e., factors that restrict the driver's vision). The acknowledgement that drivers are fallible and make mistakes, and that the road system should accommodate for these mistakes without the road users being seriously or fatally injured, is the central tenet of the concept of the Safe System (Woolley et al., 2018). Indeed, this research has also shown that it is through superior intersection design, planning and traffic management, with a view towards an eventual Safe System, that these crashes can be either prevented or the resulting injury severity reduced. There are methods (such as grade separation) through which these crashes can be completely prevented at a given intersection, or speed can be managed to survivable levels. However, inevitably, other considerations, such as cost, space, and land acquisition, are also important.

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Appendix A

A.1 Understanding the safety problem

A first line of inquiry should be to understand the safety problem at the intersection. Different information can be used to form this understanding and while some information may be available, some may be difficult to obtain or not available at all. Some examples of information that can be used to understand the safety problem are:

- Previous crash history
- Proactive safety assessments (e.g., AusRAP survey results)
- Previous road safety audits and Safe System assessments
- Other safety documentation, such as a study or register of near crash events
- Professional knowledge (e.g., from experience of those who manage the intersection)
- Community outreach (e.g., community concerns and complaints about the intersection).

It is important to use objective evidence where this is available. Subjective viewpoints, such as those from community members, may provide valuable insights but may also be biased and distract from more relevant safety issues.

When determining the safety problem, it is important to understand the prevalent mechanisms of crashes. A crash history, where present, can be assessed to determine the types of crashes that have occurred at the intersection. However, while a crash history may provide valuable objective information, it should not be used as the exclusive source of information, as it may not represent all current safety problems with the potential to result in a crash. This is of particular concern at intersections with low traffic volumes and hence lower numbers of previous crashes. Although it is crucial to conduct thorough investigations of the mechanisms of fatal and serious injury crashes (as these may differ to those of lower severity crashes), inquiry should be made into both. Regarding stop and give way sign-controlled intersections, crash mechanisms presented previously in this report are divided into two broad categories:

- Run-through crashes: caused by a failure to recognise the need to give way (e.g., did not see the give way/stop sign or did not recognise that an intersection was present)
- Fail to give way crashes: caused by not giving way to a vehicle on the major road (e.g., slowed or stopped to give way, but then pulled out in front of an oncoming vehicle).

The prevalent crash mechanisms help determine the type of treatment that is to be used.

A.2 Preliminary inspections

Whether designing a new intersection, upgrading an existing intersection, or investigating an intersection after a crash, an important line of inquiry is scrutinising the proposed or current design of the intersection. Three primary points of inquiry can be made:

1. Does the intersection conform to established design standards and guidance,
2. Does the intersection contain hazards that might increase the risk of a crash, and
3. Does the intersection minimise or eliminate the risk of fatal and serious injury crashes?

Design standards and guidance exist to ensure conformity to an at-least minimum prescribed level set out within a design domain (O'Callaghan 2021). This design domain is an historical artifact that,

while reducing the risk of injury from crashes, does not necessarily eliminate the risk of fatal and serious injury crashes. While reliance should not be placed on design standards and guidance alone to create a safe intersection environment, they ensure a minimum level of safety is obtained. It should be noted that while the design domain delineates conforming design from sub-standard and potentially harmful design, novel approaches that can effectively reduce fatal and serious injuries may exist beyond the current design domain. While conformity with the design domain is an important aspect of design, it should not come at the cost of innovation. It is important that promising novel approaches are trialled and assessed for their ability to be safely implemented. This will allow the design domain to evolve as evidence of the effectiveness of innovative treatments becomes available.

Hazards can arise from both well-known design limitations, such as sight distance constraints caused by terrain, and design oversights, like the introduction of sight distance limitations due to the placement of physical obstructions (e.g., road signs). Road safety audits (RSAs) provide a mechanism for identifying such hazards and rectifying them before they lead to a crash (Hillier, 2022). RSAs can also be used to improve safety at intersections of concern or where previous crashes have occurred. RSAs primarily focus on the detailed design of the road, making them useful for identifying safety hazards that may not have been considered during the design and construction phases. However, RSAs are less concerned with changes that can be made during the conceptualisation and proposal phases of a project. As such, they have limited potential to identify hazards within the fundamental concept of a design, such as the decision to use a roundabout over a traditional controlled intersection layout.

Alignment with the Safe System is a fundamental step in minimising the risk of fatal and serious injuries. Ensuring alignment with the Safe System requires intervention at the conceptualisation and proposal phases of a project. Delayed intervention often proves insufficient, as critical decisions, such as the intersection layout and type of control, has generally already been decided. Safe System assessments (SSAs) are a useful tool for assessing alignment with the Safe System and are most beneficial when they are instigated at the earlier stages of a project (Turner et al., 2016). SSAs can be used to understand Safe System alignment at existing or new intersections and can be used to make comparisons between different design options. They offer the greatest value when used with the intent of exploring design alternatives that align with the Safe System.