Centre for
Automotive Safety Research

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CASR REPORT SERIES
CASR007
March 2007

THE UNIVERSITY OF ADELAIDE
AUSTRALIA

Report documentation

REPORT NO.	DATE	PAGES	ISBN	ISSN
CASR007	March 2007	36	978 1 920947 08 8	1449-2237

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AVAILABLE FROM

Centre for Automotive Safety Research
http://casr.adelaide.edu.au/reports

ABSTRACT

This study examined the issue of right turn crashes at Adelaide signalised intersections through a literature review, an analysis of relevant South Australian fatal crashes, an examination of Adelaide metropolitan crashes reported to the police and some in-depth crash investigation. Such crashes were found to be relatively common and to be associated with both older and younger right turning drivers. Full control of right turn movements at all times of the day appears to be the most effective treatment. Dedicated right turn lanes and the use of red light and speed cameras may also offer some safety benefits.

KEYWORDS

Signalised intersection, Accident analysis, Accident countermeasure

Summary

This study examined the issue of right turn crashes at signalised intersections through a literature review, an analysis of relevant South Australian fatal crashes, an examination of Adelaide metropolitan crashes reported to the police and in-depth crash investigations.

Right turn crashes at Adelaide signalised intersections:

- average around 1290 crashes per year
- account for 3.2% of crashes in South Australia
- account for 3.8% of crashes in Adelaide
- account for 16.5% of crashes at Adelaide signalised intersections
- are mostly judged by the Police to be due to the right turning vehicle failing to stand (91.5%)
- appear to have been increasing in number since 1993

Right turn casualty crashes at Adelaide signalised intersections:

- average around 390 casualty crashes per year (which costs the South Australian community around $27 million per year)
- account for 5.2% of casualty crashes in South Australia
- account for 6.7% of casualty crashes in Adelaide
- account for 26.9% of casualty crashes at Adelaide signalised intersections
- are mostly judged by the Police to be due to the right turning vehicle failing to stand (91.3%)
- appear to have been increasing rapidly in number since 1993

Right turn fatal crashes at Adelaide signalised intersections:

- average around 2 fatal crashes per year
- account for 1.5% of fatal crashes in South Australia
- account for 3.5% of fatal crashes in Adelaide

Based on the review of the literature and analysis of the South Australian crash data, the following findings were made:

- Older drivers are at particular risk of being involved in a crash while turning right at a signalised intersection
- Young drivers are also at particular risk of being involved in a crash while turning right at a signalised intersection
- Full control of right turn movements at signalised intersections is a highly effective method of reducing right turn crashes at such intersections
- Partial control of right turn movements at signalised intersections (where the traffic signals control right turns for only part of the time) appears to be ineffective in reducing right turn crashes at such intersections
- Right turn arrows are most effective when also in operation during peak traffic periods
- Right turn lanes at signalised intersections appear to reduce right turn crashes as well as rear end crashes
- Red light cameras and in particular those that also measure vehicle speeds have the potential to reduce right turn crashes at signalised intersections although the literature is not currently clear on this

Most of the possible countermeasures for reducing right turn crashes at signalised intersections will also reduce the efficiency of traffic flowing through such intersections. While this issue is beyond the scope of this report, it will need to be considered if the above countermeasures are to be implemented.

Contents

1 Introduction

It is desirable for those responsible for the functioning of traffic signals to understand the nature of the crashes occurring at signalised intersections. Right turn crashes, in particular, are not well understood. The purpose of this Report was to identify ways to reduce the frequency of right turn crashes at signalised intersections.

The sponsor of this report specifically requested information in the following areas:

- the causes of 'fail to stand' right turn crashes
- the role of red light running
- the safety benefits of right turn arrows
- the safety benefits of dedicated right turn lanes
- the advisability of removing the right turn arrow during peak hours

A review of the international literature was undertaken along with an examination of Corner's files of relevant South Australian crashes. The Traffic Accident Reporting System (TARS) data on crashes at signalised intersections in the Adelaide metropolitan area was also examined together with data from at scene crash investigations.

2 Literature review

This Section reviews the research literature on factors that influence the occurrence of right turn crashes at signalised intersections with emphasis on characteristics of the driver and the system of traffic control.

Some of the studies discussed herein were conducted in Europe and the United States of America. It is assumed, in this review, that a left turn on a carriageway where vehicles travel on the right side of the road is equivalent in all aspects, other than direction, to a right turn on a carriageway where vehicles travel on the left side of the road. In this report therefore, unless directly quoting from an author(s) (and in this case a clarification will be inserted) the term "right turn" will be used to discuss the manoeuvre that requires a vehicle to turn across a lane(s) that carries oncoming traffic.

2.1 Driver factors

Turning right at a signalised intersection is one of the most difficult manoeuvres to make when driving (Abou-Henaidy, Teply, Hunt, 1994; Shebeeb, 1995). It requires a driver to assess the speed and distance away of oncoming traffic and make a judgment as to whether there is a sufficient gap in the traffic to turn right safely. Similarly, the driver of a vehicle proceeding straight through a signalised intersection has an obligation to do so at a legal speed.

Numerous factors can negatively affect a driver's ability to turn right safely. These include factors which affect a driver's perception of oncoming vehicles, willingness to accept unsafe gaps, and ability to physically carry out a right hand turn. A number of studies have investigated the driver factors which influence the likelihood of experiencing a right turn crash at a signalised intersection.

2.1.1 Older drivers

Staplin et al. (1998), in a comprehensive review of the literature pertaining to the problems faced by older drivers at intersections, provide statistical evidence that older drivers have a high probability of being involved in a right turn crash as the turning driver and establish the reasons behind this relationship. Staplin et al. write:

> *"People aged 65 and older represent about 12 percent of the population and about 14 percent of all motor vehicle fatalities. Compared to younger age groups, fewer older people have licenses, and they drive fewer miles per licensed driver. Yet, per mile driven, older drivers have higher crash rates than any other group except teenagers."*

In particular regard to right turn crashes, Staplin et al. (1998) looked at the incidence of right turn crashes at both signalised and non-signalised intersections compared to all multi-vehicle crashes across a range of age groups. The results are expressed in Table 2.1 below.

Table 2.1
Right turn crashes as a percentage of all multi-vehicle crashes by age of turning driver (Staplin et al., 1998)

Age Group (years)	< 27	27-55	56-75	76+
Right turn crashes	6.5%	6%	8.9%	11.9%

Staplin et al. also report that older drivers are over represented in right turn crashes at signalised intersections. In one set of data drivers aged 75 and over were found to be involved in 30.2% of right turn crashes compared with drivers aged 30-50 and 65-74 who were involved in 25.2% and 26.8% of right turn crashes respectively.

The results of the Staplin et al. study show that older drivers, if they are involved in a crash, are more likely to be involved in a right turn crash than are younger drivers.

Staplin et al. (1998) suggest a number of reasons why old age is related to intersection crashes and in particular, right turn crashes. In relation to crashes in general older people are more likely to have:

- Diminished sensory/perceptual capabilities
- Diminished cognitive capabilities
- Diminished physical/psychomotor capabilities
- Dementia and diminished driving skills

In particular reference to right turn crashes Staplin et al. suggest three explanations for why older people are more likely to be involved in this type of crash:

- Poorer judgement as to what constitutes a suitable gap in oncoming traffic
- Difficulty in carrying out the turning movements required to turn right at an intersection as bone and muscle mass decrease, joint flexibility diminishes and the general range of motion decreases
- Slow reaction time when responding to unexpected stimuli such as might appear before a crash, thus decreasing the likelihood that a crash is avoided

These three factors manifest themselves disproportionately in older people and for these reasons older people are more likely to be involved in a right turn crash than younger people.

2.1.2 The frustration hypothesis

Ebbesen and Haney (1973), in a series of studies, concluded that frustration increases right turn risk taking behaviour. Initially these researchers observed that when right turning drivers had traffic waiting behind them, they would accept smaller gaps in oncoming traffic (measured temporally) than when there was no other waiting traffic. The authors concluded that these drivers "took greater risks to avoid keeping other drivers waiting" (p. 314). Ebbesen and Haney also found that being forced to wait in line behind other cars for any amount of time also significantly increased the risks drivers took when turning right. They realised that this effect may have confounded their previous findings, pointing out that the longer a car waits in line, the more likely it is that another car will pull up behind it. Investigating this theory further they discovered that it was waiting time that was affecting risk taking behaviour; the presence of cars behind the observed vehicle in fact had very little effect on risk taking behaviour.

To explain their findings Ebbesen and Haney (1973) suggest what they term the "frustration hypothesis". Drivers who are forced to wait in line at an intersection to turn right become frustrated and therefore are more likely to take risks. An extension of this hypothesis could suggest that drivers who are more likely to take risks when turning right, i.e., accept smaller gaps in traffic, are more likely to be involved in a right turn crash.

2.1.3 Alcohol intoxication

It is clear that driving when intoxicated increases the likelihood of being involved in a crash (see Wilson and Mann, 1990, for a review). Early studies (Filkins et al., 1970; Neilson, 1969; Perrine, Waller and Harris, 1971; Traffic Injury Research Foundation of Canada, 1975) found that between 40% and 55% of fatally injured drivers had blood alcohol concentrations (BACs) exceeding 0.1%. Other research (Borkenstein, Crowther, Shumate, Zeil and Zylman, 1964; Lucas, Kalow, McCall, Griffith and Smith, 1955) found that between 5% and 15% of drivers involved in non-fatal crashes had BACs of 0.1% or greater. The research that has investigated the correlation between drink driving and crash incidence has consistently and clearly demonstrated that drink driving increases the likelihood of being involved in a crash.

Moskowitz and Burns (1990) suggest a number of reasons why a driver with even a low BAC (below .05%), can have an increased likelihood of being involved in a crash. They claim that alcohol impairs the following processes when driving:

Psychomotor skills: Alcohol deceases physical coordination, balance and movement. The intoxicated driver may find it more difficult to physically carry out the functions required to drive safely.

Vision: Intoxicated drivers spend more time focusing on the centre of their driving scene and are therefore less likely to see important peripheral events.

Perception: While the intoxicated driver's perception may be relatively unaffected when driving with little sensory input, i.e., on a quiet straight road, when driving in a complex environment i.e., a busy intersection, their perception of the road, road signs and other drivers is impaired. This can lead an intoxicated driver to take risks (such as accepting a smaller gap to turn into) that they would not take when sober.

Information processing: Alcohol slows the rate at which the brain can process information. When intoxicated a driver will process information slower than usual and therefore the time it takes them to respond to their environment increases.

Attention: It is vital, when driving, that drivers be able to divide their attention between two or more sources of visual information. Intoxicated drivers, when required to divide their attention between tasks, favour one task over the other and therefore the performance of the other task is particularly impaired. It is suggested that intoxicated drivers, as they focus on one source of information (e.g., conversing with a passenger) will neglect other information that is necessary to maintain control of their vehicle (Brewer and Sandow, 1980).

It is clear that drink driving increases the likelihood of being involved in a crash while performing any manoeuvre on any section of the road. But what are the particular effects that alcohol has on a driver's performance when turning right at a signalised intersection? Turning right is a complex manoeuvre that involves judgments of speed and distance, fast reaction time, the physical ability to coordinate a number of movements at the one time and attention to and perception of a variety of stimuli. These are all processes that are negatively affected by the consumption of alcohol and therefore it would appear that the intoxicated driver would be at particular risk of having a crash when turning right at a signalised intersection. Unfortunately there has been little research investigating the particular effects alcohol has on a driver's performance at signalised intersections let alone right turn crashes at signalised intersections. The only study found to touch on this subject was conducted in Australia by Corben and Young (1983).

Corben and Young (1983) conducted a study into the incidence of alcohol-related crashes at signalised intersections. They compared the different crash patterns displayed at signalised intersections by sober and intoxicated drivers (BAC of 0.05% or greater). Their results are displayed in Table 2.2, where the frequency of each crash type is shown as a per cent of overall crashes.

Table 2.2
Percent of intoxicated versus sober drivers involved in different crash types
(Corben and Young, 1983)

Crash Type	BAC < 0.05	BAC 0.05+
Right turn	42%	31%
Cross traffic	30%	21%
Rear end	8%	15%
Other	19%	33%
Total (N)	817	360

From these results it is clear that rear end and other crashes, which tended to be essentially single vehicle crashes involving a collision with a vehicle or stationary object, were over-represented in alcohol related crashes at signalised intersections. Right turn crashes in comparison were under-represented. This does not necessarily suggest that alcohol does not affect the skills needed to complete a right hand turn. Rather, the skills that are required to avoid rear end and single vehicle crashes appear to be affected to a greater degree by alcohol consumption than those involved in turning right.

It is possible, although Corben and Young (1983) do not mention it, that right turn crashes were under-represented because intoxicated drivers have more opportunities to fail at less complex manoeuvres, like avoiding parked cars, staying on the road and stopping behind parked cars, than turn right manoeuvres. In comparison to these simple tasks, right turn movements are relatively infrequent. However, further studies are required to determine the extent to which alcohol impairs a driver's ability to turn right safely at a signalised intersection.

2.1.4 Speed

A wide range of research supports the claim that driving at high speed is associated with a high risk of crash involvement (see: Cirillo, 1968; Cleveland, 1959; DeSilva, 1940; Fieldwick and Brown, 1987; Fildes, Rumbold and Leening, 1991; Finch, Kompfner, Lockwood and Maycock, 1994; Godwin, 1992; Lefeve, 1956; Research Triangle Institute, 1970; Sliogeris, 1992; Solomon, 1964; Transportation Research Board, 1984; Wasielewski, 1984; West, French, Kemp and Elander, 1993; Wilson and Greensmith, 1983). Reports from America have found that speeding or excessive speed is involved in about 12% of all crashes reported to the police and one third of fatal crashes (Bowie and Walz, 1991). Reports in Australia have found that speeding or excessive speed contributes to approximately 20% of fatal crashes (Haworth and Rechnitzer, 1993). A study conducted in Adelaide by Kloeden, McLean, Moore, and Ponte (1997) found that travelling above 60 km/h in a 60 km/h speed limit zone increases the risk of involvement in a casualty crash. The risk approximately doubles with each 5 km/h increase in travelling speed. All of these studies have found that speeding increases the risk of being involved in a crash, and in particular a fatal crash, on all parts of the road.

In specific regard to the relationship between speeding and right turn crashes at signalised intersections, little research has been done. However a number of inferences can be made from the general study of speed and how it contributes to crashes. In addition, some research (Hills, 1980; Hills and Johnson, 1980) has discussed the possibility that failures in perception are often involved in crashes involving a speeding vehicle. This research is of particular relevance to the discussion of speed and right turn crashes as failures in perception caused by driver expectancies would appear to explain how speed contributes to right turn crashes. Also some research (McLean, Offler and Sandlow, 1979) provides tentative statistical evidence for the possible involvement of speed in right turn crashes.

Kloeden et al. (1997) suggest a number of factors that contribute to speed increasing the risk of involvement in a casualty crash: increased reaction distance and braking distance, increased impact speed and crash energy, increased chance of losing control of the vehicle and inappropriate driver expectancies. This last factor, driver expectancies, is of particular relevance to speed and its involvement in right turn crashes at signalised intersections. Drivers travelling at high speed can create dangerous situations when a turning driver assumes that a speeding through car is travelling at the speed limit. Research (Hills and Johnson, 1980) has suggested that turning drivers often choose gaps in traffic through which to turn right based on a function of the distance between themselves and oncoming traffic and the prescribed speed limit rather than the actual speed of the oncoming traffic. Therefore, when an approaching car is speeding, right turning drivers at signalised intersections may underestimate the amount of time they have to turn right safely.

Hills and Johnson (1980) found that drivers intending to turn right across a carriageway, when asked to estimate the speeds of approaching vehicles, on average, underestimate the speed of fast moving vehicles and overestimate the speed of slow moving vehicles. At an intersection with an approach speed of 40 mph drivers judged vehicles travelling at between 60 and 69 mph to be travelling on average 14 mph slower than they actually were. Hills suggests that drivers have expectations in regards to the travelling speed of other vehicles and this influences judgements of their speed. When turning right across a carriageway with a speed limit of 40 mph drivers expect other vehicles to be travelling at about that speed. When a car considerably exceeds the speed limit, drivers appear to recognise that the vehicle is travelling above the speed limit but underestimate its actual speed and may misjudge the time available to turn right across the road safely. In regard to right turn crashes at intersections, this study suggests that when an oncoming vehicle is speeding, right turning drivers are likely to misjudge the time they have to turn across the carriageway safely.

Some evidence that speeding contributes to the likelihood of being involved in a right turn crash at a signalised intersection is provided in an in-depth study carried out by McLean et al. (1979). Although in no way conclusive, the results of a part of this study provide some statistical evidence to suggest that speed is causally related to right turn crashes. McLean et al. found, in a study consisting of crashes at stop sign controlled intersections, that drivers on the though road were four times more likely to have received a conviction for speeding than the drivers entering the intersection from the stop sign. This result can be interpreted in various ways, one of which is that vehicles travelling on the through road, given their history of speeding, were likely to be speeding directly before the crash occurred. While no definite conclusions can be made from this study it does suggest that speeding contributes to crashes in which the driver of one vehicle must judge an appropriate gap in passing traffic, as is the case for right turning drivers at permissive right turn signalised intersections.

2.2 External factors

In an attempt to improve the safety of intersections, there has been much research done into the various external factors that may influence the likelihood of experiencing a right turn crash at a signalised intersection. The following Sections will discuss these variables and how they affect right turn crashes at signalised intersections.

2.2.1 Traffic flow

One of the most important and most obvious factors influencing the number of right turn crashes occurring at a signalised intersection is traffic flow. Simply stated, the more oncoming traffic and right turning traffic there is flowing through an intersection, the more right turn crashes will be expected to occur. Traffic flow has long been considered an important determinant of right turn crash involvement (see: Asante, Ardekani and Williams, 1993; Bui, Cameron and Foong, 1991; Mustafa, Pitslava-Latinopoulou and Papaiouanou, 1992; Stamatiadis, Kenneth and Agent, 1997; Upchurch, 1991).

Numerous studies control for traffic flow while looking at the relationship between crash rates and other variables but few authors report the actual influence traffic flow has on crashes at intersections. An exception, Ogden, Newstead, Ryan and Gantzer (1994), report that traffic flow accounts for about 21% of the variation in crash rates between intersections (statistical significance not provided). When considering the many variables that may affect a crash at a signalised intersection, this finding supports the idea that traffic flow is a significant determinant of crashes at signalised intersections and, hence, right turn crashes at signalised intersections.

2.2.2 Right turn phasing

Researchers tend to conclude that right turn crash rates are reduced under a fully controlled phasing system. Taylor (1991), for example, considered the trade off between efficiency and safety that occurs by installing such a system:

"[At] off-peak the differences in mobility performance between alternative right turn control regimes are small, suggesting that the considerable safety benefits found for full control should be of primary concern. At peak periods, partial control may offer mobility advantages, but at all other times the gains from partial control instead of full control are not significant" (p. iii).

The National Association of Australian State Road Authorities lists a number of circumstances under which fully controlled phasing should be installed at an intersection. One of these is when "accident experience at the site indicates turning traffic is unable to detect sufficient gaps in which to turn" (1987, p. 28). Authorities agree that protected right turn phasing reduces right turn crash rates.

There are four basic methods used to control the movement of right turning vehicles at signalised intersections:

1. Fully controlled (also termed fully protected) where all right turns are controlled by traffic lights so that turning drivers do not have to cross oncoming traffic
2. Partially controlled (or permissive/protected) where right turns are controlled by traffic lights for some of the light phase and filter turns are allowed at other times during the light phase
3. Permissive (also referred to as permitted or filter turn) where all right turns are filter turns
4. No right turn

Also some intersections can use different methods at different times of the day or day of the week.

The safety provided by a fully controlled phasing system comes about because right turning drivers no longer have to determine safe gaps in oncoming traffic. Many of the driver factors mentioned in the above Section such as age, speed and frustration, which may lead to the acceptance of unsafe gaps in oncoming traffic, are avoided as drivers have priority over other traffic on a green arrow.

Studies conducted by Asante et al. (1993), Mustafa et al. (1992), and Stamatiadis et al. (1997), compared crash rates at intersections with different right turn phasing patterns, including: fully controlled, partially controlled and permissive right turn systems. Unfortunately, these authors failed to control for a number of important variables and the results of their studies are therefore questionable. If a meaningful comparison is to be made between intersections with different phasing patterns, the intersections need to be matched on important confounding variables such as vehicle flow, the number of opposing lanes and other relevant system features. The previously mentioned authors did not control for these variables. While flow rate has been controlled for in two of these studies (Mustafa et al.; and Stamatiadis et al.) no other factors have been. Therefore, the comparisons of these different phasing systems are likely to have provided limited findings as the particular effect of the right turn phasing system could not be fully isolated. This problem is amplified when we consider that fully controlled right turn systems are often installed at intersections with uncommonly high right turn crash rates.

While the results of studies conducted by Asante et al. (1993), Mustafa et al. (1992) and Stamatiadis, et al. (1997), have been influenced by confounding variables, certain predictions can still be made from these studies. Fully controlled intersections tend to have a higher number of crashes than intersections under other phasing systems as fully controlled systems are often installed at problem intersections. Despite this Asante et al. and Stamatiadis et al. found that intersections with protected phasing patterns generally had lower right turn crash rates than partially controlled intersections. Mustafa et al. found that fully protected intersections had significantly fewer right turn crashes than intersections with a permitted right turn control. These findings suggest that a fully controlled phasing pattern can reduce right turn crashes, even at intersections exhibiting high right turn crash rates and, as would be expected, can be safer than both permissive and partially controlled intersections.

Upchurch (1991) used a before and after design to determine the effects that changes from fully protected to partially protected control systems and no control to partially protected control systems had on crash rates. This design increases the validity of the study by avoiding the problem of having to match different intersections on relevant variables but it is subject to regression to the mean effects if high crash rate intersections were chosen for treatment (it was not clear in the paper if this was the case or not). In this type of study factors like traffic flow and general design features should remain relatively constant between the before and after groups. Unfortunately, Upchurch also investigated the effects of leading and lagging right turn systems and the number of opposing lanes faced by right turning traffic (two or three). Upchurch ended up with 16 before and after groups all containing relatively small sample sizes, the majority of groups containing 12 or less studied intersection approaches. No significant changes in crash rates are mentioned and the trends found in the data are often contradictory. Generally it appears that changes from permissive to protected or partially protected phasing systems lead to reductions in right turn crashes. But little can be made out from this tangle of information.

Warren (1985) also used a before and after design to measure the effects of changing right turn control systems from protected to partially protected. Also suffering from a limited sample size (the experimental condition includes 7 intersections and 14 approaches) the results of this study are limited and the observed differences in the numbers of crashes were not found to be statistically significant despite the existence of some large effects. Warren found that right turn crashes doubled with the change from protected to partially protected phasing systems. When comparing this change with the control group, right turn crashes appear to have increased four fold, as control group rates had decreased over the same time. Warren also investigated what effect this change from protected to partially protected phasing had on rear end crashes. Warren suggested that protected phasing systems result in higher rear end crash rates as delay times increase under this type of phasing control. No evidence for this claim is provided. Warren reports that rear end crashes decreased by 30% with the introduction of partially protected phasing systems, however, rear end crashes at control intersections were also reduced by 30% over the same time, suggesting no real effect. The results of the study suggest that a protected phasing system is far safer than a partially protected phasing system; it reduces right turn crashes and does not adversely affect rear end crashes.

Bui, Cameron and Foong (1991) avoid the design problems faced by the previously mentioned studies. Like Upchurch (1991) and Warren (1985) these researchers compared crash rates at the same intersection before and after different phasing systems were installed. Unlike these authors, Bui et al. used appropriate sample sizes (218 approaches over three groups) and unlike Upchurch they employed a simple design and included a control sample against which to measure any general changes in crash rates and controlled for regression to the mean effects. Bui et al. investigated changes in right turn crashes at intersections that had undergone three types of phasing change:

- No control to partially controlled
- No control to fully controlled
- Partially controlled to fully controlled

Bui, Cameron and Foong (1991) found that a partially controlled phasing pattern had no significant safety benefits over having no right turn control. They also found that a fully controlled right turn provided large and statistically significant improvements over both partially controlled and uncontrolled right turn systems. The changes in crash rates for these two changes are displayed in Table 2.3.

Table 2.3
Per cent reduction in crashes by type of crash
(Bui, Cameron and Foong, 1991)

Change	Overall	Right Turn	Cross Traffic	Pedestrian	Rear End
No Control - Partial Control	5% (NS)	-18% (NS)	23% (NS)	28% (NS)	8% (NS)
No Control - Full Control	45% **	82% **	48% *	35% (NS)	-72% **
Partial Control - Full Control	65% **	93% **	51% *	-32% (NS)	9% (NS)

(NS) = non significant * = $p < 0.05$ ** = $p < 0.01$ - = increase

These researchers observed significant reductions in crash rates when fully controlled phasing systems were introduced. For example, intersections that changed from having a partially controlled right turn system to a fully controlled system and intersections that changed from having an uncontrolled right turn to a fully controlled system exhibited an average saving of 1.52 and 0.98 right turn casualty crashes per intersection per year respectively. This study was thorough and well controlled and provides strong support for the theory that controlled right turn phasing signals can significantly reduce right turn crashes.

The counterintuitive result of this study was the finding that partially controlled systems seem to offer no safety benefit over having no control. Bui et al. speculated that the high volumes of traffic at the examined intersections meant that similar numbers of vehicles were turning during the filter turn phase of a partially controlled intersection as were turning when the intersection was previously uncontrolled leading to similar numbers of right turn crashes. This is unconvincing as a complete explanation without detailed traffic flow counts which were not available. An additional explanatory factor could be driver confusion with the light sequence at a partially controlled intersection: a green right turn arrow followed by a red right turn arrow followed by no arrow could lead some drivers to believe they have right of way when the red arrow goes out which could result in additional crashes that counteract the benefits of the controlled phase.

The increase in rear end crashes that occurred in the study conducted by Bui et al. is noted by the authors but no suggestions are made as to why the effect occurred. Further investigation is required. At the moment however, this finding must be viewed in context. First, the effect does not appear to be robust as it was not detected in the condition investigating changes in crash rate between intersections that changed from fully controlled to partially controlled phasing systems. Secondly, the only other study investigating the effects of different phasing control systems on crash rates to have included an analysis of rear end crashes is Warren (1985) who found no real change in rear end crashes between partially controlled and fully controlled intersections. Thirdly, accepting the result, it should be noted that overall crashes still exhibited a large and statistically significant reduction when fully controlled phasing systems were installed. Fourthly, rear end crashes tend to be less severe than right turn crashes. Therefore, again accepting that fully controlled phasing systems increase rear end crashes, there should still be an overall saving in terms of the crash severity at any intersection at which such a system is installed.

The literature tends to confirm the idea that fully controlled right turn phasing reduces right turn crashes compared to partially or uncontrolled systems. Partially controlled systems seem to offer no safety benefit to having no control. While a number of the studies that have investigated this phenomenon are limited in their design or have failed to find statistically significant effects, taken together they support the theory that fully controlled right turn phasing decreases right turn crash rates. An exception to these poorly designed studies, the study by Bui, Cameron and Foong (1991), confirms this theory. The study conducted by Bui et al. also raises the possibility that fully controlled phasing systems may increase rear end crashes. As yet there is not enough evidence to support the validity of this finding. It is clear that fully controlled right turn phasing can be used effectively to significantly decease right turn crashes and improve the general safety of signalised intersections.

2.2.3 Removing the right turn arrow at peak hour

In choosing any one particular phasing control system there is always a trade off between the goals of safety and efficiency in terms of mobility. Fully controlled phasing signals are associated with a reduction in traffic flow while permissive and partially controlled phasing signals have been found to enhance traffic flow and improve the capacity of an intersection. Therefore, it is sometimes suggested that the right turn arrow at intersections with fully controlled phasing systems be removed, i.e., be made permissive during peak hours to promote efficiency. However, as has been mentioned previously, high traffic flows are associated with high numbers of right turn crashes. Research clearly illustrates that traffic crashes are at their highest during peak traffic flow periods. Ogden and Newstead (1994) have found that crash rates at signalised intersections peak first between 8:00am and 9:00am and again between 5:00pm and 6:00pm. Considering the demonstrated effectiveness of fully controlled right turns in reducing right turn crash rates, it would be during these times that this phasing system would prevent the greatest number of right turn crashes. If the goals of efficiency at a given intersection are so great that a protected phasing system can not be employed during peak hour, it is suggested that, where feasible, a right turn ban be implemented rather than the removal of right turn protection.

2.2.4 Designated right turn lanes

While right turning lanes are sometimes installed simply to increase the capacity of an intersection, research suggests that they can also decrease right turn crash rates. A number of studies have investigated the effectiveness of right turn lanes in relation to safety, generally finding them to significantly reduce right turn and rear end crashes. Both Hammer (1969) and McCoy and Malone (1989) found that installing dedicated right turning lanes at signalised intersections significantly decreased both right turn and rear end crashes. McCoy and Malone report that on average there were 0.28 crashes per one million vehicles performing a right-hand turn at signalised intersections where dedicated right turn lanes were not installed, and 0.096 crashes per one million vehicles performing a right-hand turn at intersections where dedicated right turn lanes were installed. This was found to be a statistically significant ($p < 0.05$) 66% saving in right turn crashes. There was also found to be a 59% ($p < 0.05$) reduction in rear end crashes at signalised intersections where dedicated right turn lanes were installed. The study conducted by Hammer confirms these findings. Hammer reports that right turn and total crashes were reduced significantly by 54% and 17%, respectively, at intersections where dedicated right turn lanes were installed. However, other researchers have not obtained such conclusive results.

Researchers such as Agent (1979), Foody and Richardson (1973) and Ogden, Newstead, Ryan and Gantzer (1994) have found trends to suggest that dedicated right turn lanes reduce right turn crashes however these results have not been statistically significant. Foody and Richardson report a reduction of 39% in right turn crashes and a 9% reduction in total crashes at signalised intersections where dedicated right turn lanes were installed. Agent found that the right turn crash rate was 54% lower at signalised intersections where dedicated right turn lanes were installed however this was not a statistically significant (at the 5% level) reduction. The Australian study conducted by Ogden et al. explored numerous factors believed to influence crash rates at signalised intersections. One of these factors was the presence of dedicated right turn lanes, which they found to be more frequently associated with safer intersections than unsafe intersections. These researchers report that 56% of intersections classified as having low crash rates had dedicated right turn lanes while only 42% of intersections with high crash rates had dedicated right turn lanes. These results suggest that dedicated right turn lanes are associated with safer intersections, but a direct comparison of groups and significance testing would be required to confirm this finding. The studies conducted by Agent; Foody and Richardson; and Ogden et al. have shown that dedicated right turn lanes reduce right turn crash rates substantially, however, none of these findings was shown to be statistically significant.

An anomaly in this body of research is a study conducted by David and Norman (1975). This study explored the relationships between various roadway conditions and crash rates and it was found that intersections with dedicated right turn lanes which also had either an opposing dedicated right turn lane or an uncontrolled signal phasing system were associated with high crash rates. While these results deserve some further investigation it should be noted that this was an exploratory study. It should also be noted that the above mentioned studies (Agent, 1979; Foody and Richardson, 1973; Hammer, 1969; McCoy and Malone, 1989) also studied intersections with uncontrolled signal phasing patterns and found dedicated right turn lanes to improve intersection safety. The David and Norman study provides directions for further research but the weight of evidence provided by the numerous studies mentioned previously suggests that dedicated right turn lanes are effective in reducing right turn crash rates at signalised intersections.

A number of factors could be suggested to explain this effect. In reference to a previously mentioned study conducted by Ebbesen and Haney (1973) which found that waiting time increases unsafe gap acceptance, it could be suggested that dedicated right turn lanes improve the efficiency of an intersection and therefore drivers experience less frustration and accept safer gaps in oncoming traffic. Also, drivers who use a dedicated right turn lane may feel less pressure to turn right as they are not holding up any cars moving straight through the intersection. These drivers will also be less likely to accept an unsafe gap in oncoming traffic.

Designated right turn lanes also reduce the number of rear end crashes by removing the turning vehicles from the main traffic steam.

2.2.5 Red light cameras

Red light cameras primarily target deliberate red light runners, with a resulting fine when a vehicle enters an intersection on a red light. A monetary fine may also heighten driver's awareness of traffic signals thus deterring accidental red light running and red light running caused by distraction. The literature that has investigated the effects that red light cameras have on crash rates is inconclusive and often contradictory.

Studies that have investigated the effectiveness of red light cameras have also tended to focus on the effects cameras have on right angle and rear end crashes, generally ignoring the possible effects that they may also have on right turn crashes. South et al. (1988) wrote that "right-against (right turn) accidents were unlikely to be affected by the cameras as they often do not involve run-the-red offences" (1988, p. 7). This seems to be a general assumption adopted by researchers although no statistical or theoretical evidence has been provided to support this claim. In theory red light cameras should reduce right turn crashes as through drivers are more likely to stop on a yellow or red light, thus reducing the likelihood that a right turning vehicle will be struck by a late through vehicle. However, a counter effect may occur as right turning drivers, aware of a red light camera, accept dangerous gaps in oncoming traffic so as to escape the intersection before the red light appears.

Two studies have been identified in which the effects that red light cameras have on right turn crashes have been investigated. Mann et al. (1994) report that red light cameras reduced right turn crashes by 37.8%, while at control intersections, over the same time period, right turn crashes decreased by 18.7%. The difference in crash rate reduction was not found to be statistically significant (actual p not provided). It is possible that this slight effect, was the result of a regression to the mean effect. South et al. (1988) report that right turn crashes increased by 2% ($p > 0.05$) with the installation of red light cameras. It should be noted that these findings may have been affected by extraneous variables, in particular, both experimental and control intersections were structurally improved over the time of the investigation. On balance these reports, while inconclusive, indicate that red light cameras have little or no effect on reducing right turn crashes. However, these studies have not investigated this effect in detail and further research, which examines the relationship between red light cameras and right turn crash rates in more depth and effectively controls for extraneous variables, will be required to determine whether red light cameras have an effect on right turn crash rates.

2.3 Literature summary

To summarise the results of the literature review:

- Older drivers seem particularly susceptible to being involved in a collision when turning right at signalised intersections
- Drivers who have to wait longer at intersections are more likely to attempt a high risk turn through a small gap in the traffic
- While alcohol use increases all types of crash rates there is no evidence to suggest that right turn crashes are disproportionately affected
- There is some evidence that speeding by the through vehicle may play an important role in right turn crash causation
- Greater traffic flow increases right turn crashes through increased exposure
- Full control right turns through the use of turning arrows is a highly effective way of greatly reducing right turn crashes at signalised intersections although they may be associated with increased rear end crashes
- Partially controlled right turns, which occur when the signal phasing system provides a short term turning arrow followed by a period of uncontrolled filter turns, appear to provide little or no benefit over fully uncontrolled filter turns (although this result is based on only one study, it was a reasonably well designed study)
- Removing right turn arrows at peak hours is inadvisable from a safety perspective as these are the times when controlled right turns can be used most effectively to prevent right turn crashes
- Designated right turn lanes have been found to not only reduce rear end crashes but also right turn crashes although these results are not clear cut
- It is unclear from the literature that the use of red light cameras at controlled intersections reduces right turn crashes although they do seem to increase the overall safety at such intersections

3 South Australian fatal crashes

South Australian Coroner's files of all fatal car occupant crashes in South Australia from 1985 to 1996 and all fatal motorcycle rider crashes in South Australia from 1985 to 1990 were interrogated for crashes involving a right turning vehicle at an Adelaide signalised intersection.

Only 24 such crashes were found. The low number can be related to the following factors:

- Adelaide metropolitan crashes are mostly in 60 km/h speed zones
- Turning vehicles are generally travelling slowly while turning
- Through vehicles usually sustain the impact on the front
- Turning vehicles usually sustain the impact on the left side

Vehicles generally provide good occupant protection for frontal impacts and impacts to the left side are not very hazardous for the driver of the vehicle. Hence the majority of fatalities in these crashes were left side passengers (adjacent to the impact on a turning vehicle) and motorcycle riders (no vehicle crash protection).

A summary of these 24 cases is presented in Table 3.1. Four cases involved through vehicles disobeying a red traffic signal and colliding with vehicles turning on a green arrow. Three other cases involved vehicles turning against a red turning arrow.

The remaining 17 cases all involved filter turns where the turning vehicle failed to give way to oncoming traffic. In 7 of these cases, the signals had changed to yellow and in 10 the signals were green in both directions. It is interesting to note that at 8 of these intersections there were turning arrows present but they were either not operational at the time or they had gone out leaving a normal filter turn.

Table 3.1
Right turn fatal car occupant crashes (1985-1996) and fatal motorcycle rider crashes (1985-1990) at Adelaide signalised intersections

Turning vehicle					Through vehicle							Other factors
Vehicle type	Driver sex/age	Signal colour	Driver error	Fatality	Vehicle type	Driver sex/age	Signal colour	Driver error	Fatality	Speed limit	Est. speed	
Car	22M	green	fail to stand		MC	43M	green		rider	60	50-70	Red right turn arrow went out leaving a green orb, turning driver did not see MC
Car	24F	green	fail to stand	LR*	MC	23M	green			60	60-70	No turning arrow present, turning driver did not see MC
Van	25M	green	fail to stand	driver	utility	42M	green		driver	60	55-60	Right turn arrow not in operation at time of crash
Car	30M	green	fail to stand	LF**	bus	54M	green			60	60	Right turn arrow not in operation at time of crash
Car	33F	green	fail to stand	LF,LR,CR	truck	38M	green			60	40-50	Red right turn arrow went out leaving a green orb
Car	61F	green	fail to stand	driver	car	24M	green			60	60-80	Right turn arrow not in operation at time of crash
Car	66F	green	fail to stand	LF	car	72M	green			60	50	No turning arrow present, turning driver did not see car
Car	81M	green	fail to stand	LF	car	22M	green			60	60-65	No turning arrow present, turning driver stalled vehicle
Car	82M	green	fail to stand	LF	car	38M	green			60	60	Right turn arrow not in operation at time of crash
Car	??M	green	fail to stand	LR,CR***	car	??M	green			60	60-	No turning arrow present, turning driver stopped mid-intersection for oncoming bicyclist
Car	17M	amber	fail to stand	driver,LF	semi	35M	amber			60	60	No turning arrow present, turning driver was inexperienced learner driver with inexperienced instructor
Car	21M	amber	fail to stand		MC	28M	amber		rider	60	60+	Turning arrow had failed, turning driver did not see MC
Car	23M	amber	fail to stand	LR	car	42F	amber			60	60	No turning arrow present
Car	30M	amber	fail to stand	driver	4WD	21M	amber			60	65	Right turn arrow not in operation at time of crash
Car	72M	amber	fail to stand	driver	semi	50M	amber			60	60	Right turn arrow not in operation at time of crash
Car	80M	amber	fail to stand	LF	car	24M	amber			60	60-70	No turning arrow present
Car	81M	amber	fail to stand	LF	car	27M	amber			80	70-130	No turning arrow present, turning driver not wearing glasses, through driver accelerated through light
Car	20M	red arrow	disobey lights		MC	40M	green		rider	60	60-	
Car	64F	red arrow	disobey lights	LF	car	18M	green			60	60	Turning driver did not see red arrow or no turning sign
Car	72M	red arrow	disobey lights	LF	car	22M	green			60	60	
MC	24M	green arrow		rider,pillion	car	22M	red	disobey lights		60	65+	Through driver had BAC of 0.16
Car	58M	green arrow		driver	car	16M	red	disobey lights		60	160	
Car	22M	green arrow		LF	semi	17M	red	disobey lights		80	80+	Advance light warning signals ignored (same intersection as below)
Car	27M	green arrow		driver	semi	23M	red	disobey lights		80	85	Advance light warning signals ignored (same intersection as above)

Notes: * LR: Left Rear Passenger
** LF: Left Front Passenger
*** CR: Centre Rear Passenger
Estimated speeds are from the Coroner's report

4 South Australian casualty crashes

Analysis of the Traffic Accident Reporting System (TARS) database was undertaken to characterise Adelaide metropolitan signalised intersection casualty crashes and in particular, right turn casualty crashes at these intersections.

4.1 Crash selection

TARS data for the years 1981 to 2002 were used to obtain an historical overview and data for the years 1998 to 2002 were analysed in detail. The following sequential selections were made:

- All casualty crashes in South Australia between 1998 and 2002 (any injury to any participant in the crash)
- Selected only those crashes occurring within the Adelaide statistical division
- Selected only those crashes occurring at an intersection
- Selected only those intersections controlled by traffic signals
- Selected only those crashes classified as right turn crashes
- Selected only those crashes where the crash error was "fail to stand"
- Selected only those crashes with exactly one turning vehicle and exactly one vehicle proceeding straight ahead (this enabled the characteristics of the turning and straight through vehicles to be compared which is not possible in the TARS database where there are multiple vehicles executing the same manoeuvre since vehicle contacts are not recorded)

Table 4.1 shows the number of casualty crashes at each stage of the selection process and their proportions of all casualty crashes in South Australia and the Adelaide metropolitan area.

Table 4.1
Casualty crash selection process
South Australia 1998-2002

Selection process	Number	Per cent of all SA casualty crashes	Per cent of all Adelaide casualty crashes
All SA casualty crashes	37476	100.0	-
Crash in Adelaide statistical division	29318	78.2	100.0
Crash at intersection	16476	44.0	56.2
Intersection controlled by traffic signals	7269	19.4	24.8
Right turn crash	1953	5.2	6.7
Fail to stand crash	1784	4.8	6.1
Identifiable vehicles	1724	4.6	5.9

4.2 Adelaide signalised intersection casualty crashes

Table 4.2 shows the types of casualty crashes occurring at Adelaide signalised intersections. While rear end casualty crashes form the single largest group, right turn crashes form the next largest accounting for nearly 27 per cent of casualty crashes at Adelaide signalised intersections.

Table 4.2
Casualty crash types at Adelaide signalised intersections 1998-2002

Crash type	Number	Per cent
Rear end	3337	45.9
Right turn	1953	26.9
Right angle	1058	14.6
Hit pedestrian	354	4.9
Side swipe	251	3.5
Hit fixed object	169	2.3
Head on	64	0.9
Roll over	43	0.6
Other	24	0.3
Hit parked vehicle	10	0.1
Left road out of control	6	0.1
Total	7269	100.0

4.3 Adelaide signalised intersection right turn casualty crashes

Table 4.3 shows the police assigned crash error for right turn casualty crashes at Adelaide signalised intersections. By far the most common assigned error was "fail to stand" which is of primary interest in this report. The "fail to give way" crash error does not apply to a normal right turn crash and the two cases observed may be due to errors in coding or exceptional circumstances. They are excluded from this point on.

Table 4.3
Crash error in right turn casualty crashes
at Adelaide signalised intersections 1998-2002

Crash error	Number	Per cent
Fail to stand	1784	91.3
Disobeyed traffic signals	167	8.6
Fail to give way	2	0.1
Total	1953	100.0

4.4 Adelaide signalised intersection fail to stand right turn casualty crashes

Table 4.4 shows the crash injury severity of fail to stand right turn casualty crashes at Adelaide signalised intersections and compares the distribution with that for all Adelaide casualty crashes. It is apparent that such right turn casualty crashes tend to be more severe than Adelaide casualty crashes in general.

Table 4.4
Severity of signalised intersection fail to stand right turn casualty crashes
compared to all casualty crashes in Adelaide 1998-2002

Crash Injury Severity	Number	Per Cent	All Adelaide casualty crashes (%)
Private Doctor	397	22.3	41.8
Hospital Treated	1175	65.9	45.8
Hospital Admitted	209	11.7	11.4
Fatal	3	0.2	1.0
Total	1784	100.0	100.0

The economic costs of these casualty crashes was calculated to be $27 million per year (using the costs in Baldock and McLean 2005).

Figure 4.1 compares the number of right turn casualty crashes over time with all Adelaide casualty crashes as a percentage of the 1981 numbers. Since 1993, it appears that right turn casualty crashes have been rising at a much greater rate. We do not know why this is the case but it may be related to factors such as: an increase in the number of signalised intersections; greater volumes of traffic through signalised intersections; changes in the control of right turns at signalised intersections; and changes in the coding practices that identify right turn crashes in the TARS database.

Figure 4.1
Change in Adelaide signalised intersection fail to stand right turn casualty crash numbers over time compared to changes in all Adelaide casualty crash numbers

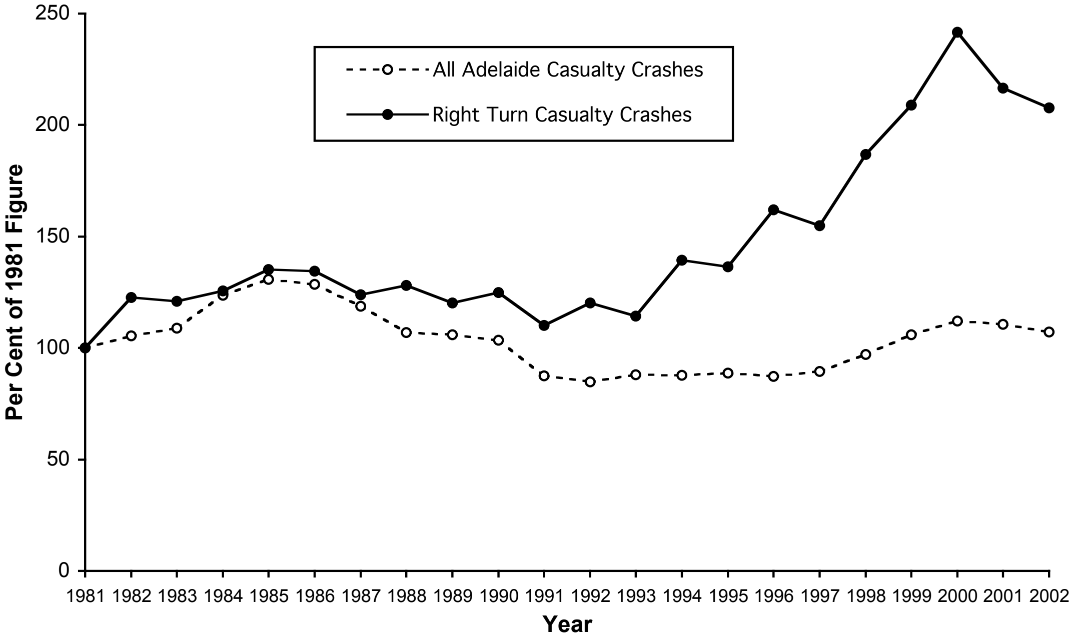


Figure 4.2 compares the distribution of right turn casualty crashes by hour of day with that for all Adelaide casualty crashes. While the right turn crash distribution has a roughly similar shape to that for all crashes, there is hardly any morning peak and the evening peak is not as pronounced and extends later into the evening. We do not know the reasons for these differences but they may be related to: some elimination of right turns at peak hours; a greater proportion of drivers not undertaking right turns at peak hours; and traffic congestion creating safe gaps for right filter turns at peak hours.

Figure 4.2
Hour of day of Adelaide signalised intersection fail to stand right turn casualty crashes compared to all Adelaide casualty crashes 1998-2002

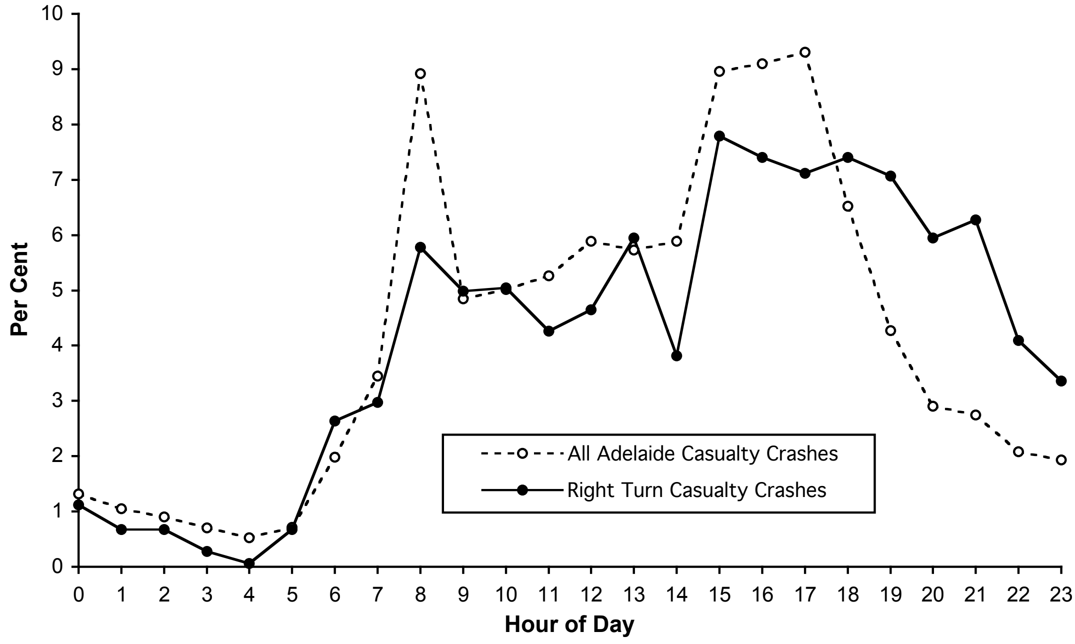
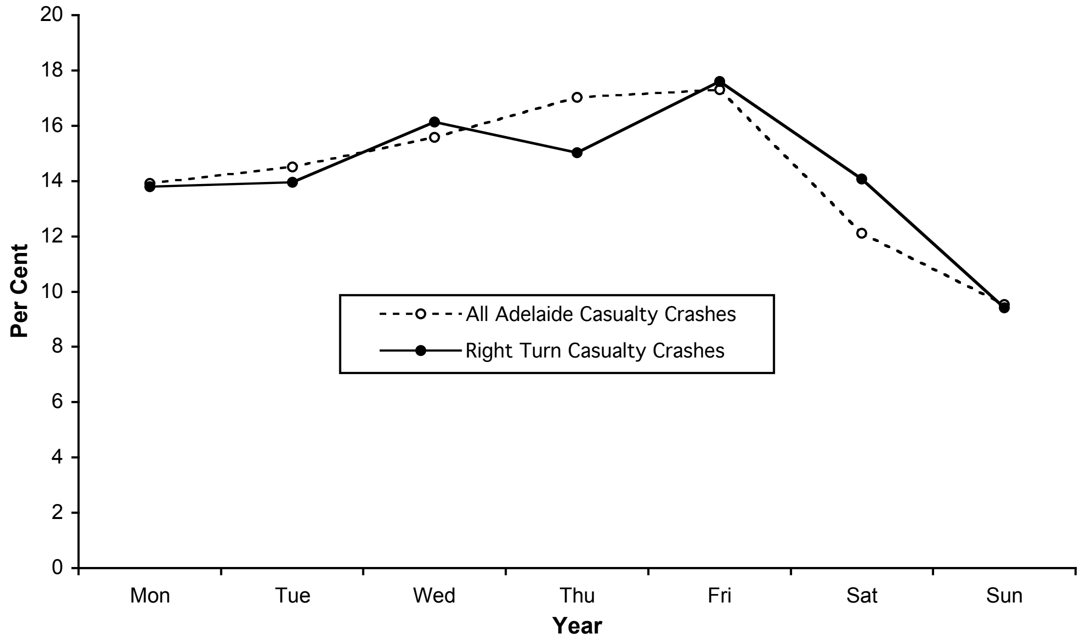


Figure 4.3 compares the distribution of right turn casualty crashes by day of week with that for all Adelaide casualty crashes. Both distributions are very similar with rates generally rising through the week and dropping on the weekend.

Figure 4.3
Day of week of Adelaide signalised intersection fail to stand right turn casualty crashes compared to all Adelaide casualty crashes 1998-2002



4.5 Comparing turning and through vehicles and drivers

It is instructive to compare the type of the turning vehicle with the type of the through vehicle. However, due to limitations in the way that the TARS database is coded, these vehicles cannot be identified when there are more than two vehicles involved. Therefore, for the following analyses, only those crashes with exactly one turning vehicle and exactly one vehicle proceeding straight ahead were selected. This amounts to 1724 out of the 1784 fail to stand right turn casualty crashes (96.6%).

Table 4.5 shows the types of turning and through vehicles involved in the right turn casualty crashes. By dividing the number of turning vehicles of a given type by the number of through vehicles of a given type we get a ratio. If the ratio is greater than 1 then that type of vehicle is more likely to be a turning vehicle than a through vehicle and conversely if the ratio is less than 1 then that type of vehicle is more likely to be a through vehicle than a turning vehicle.

Table 4.5
Comparing turning and through vehicle types for
Adelaide signalised intersection fail to stand right turn casualty crashes 1998-2002

Type	Turning (A)	Through (B)	Ratio (A/B)
Utility	44	38	1.16
Station Wagon	208	186	1.12
Car	1325	1241	1.07
Semi Trailer	11	11	1.00
Truck	14	15	0.93
Panel Van	44	49	0.90
Taxi Cab	16	26	0.62
Omnibus	5	11	0.45
Motorcycle	13	69	0.19
Pedal cycle	10	55	0.18
Other/Unknown	34	23	-
Total	1724	1724	1.00

Cars and car derivatives appear slightly more likely to be turning vehicles while motorcycles and pedal cycles are substantially more likely to be through vehicles. The motorcycles and pedal cycles are probably over represented as through vehicles since they are smaller vehicles which are harder for the driver of a turning vehicle to see. Buses and taxis may be entering intersections late in an attempt to reduce travel time while, to a lesser extent, trucks may have trouble slowing for signal changes. Buses may have trouble slowing for signal changes and may have a lower exposure to right turns without traffic signal assistance.

Table 4.6 compares the ratio of being a turning driver compared to a through driver by the sex of the driver. There is a clear distinction whereby females are more likely to be turning drivers and males are more likely to be through drivers ($\chi^2 = 20.19$, $p < 0.001$). We do not know the reason for this difference but it may be related to: males having a better spatial sense than females for picking gaps; males being more likely to speed through an intersection especially on a yellow or red light; and females being more likely to take right turns than males.

Table 4.6
Comparing turning and through driver sex for
Adelaide signalised intersection fail to stand right turn casualty crashes 1998-2002

Type	Turning (A)	Through (B)	Ratio (A/B)
Male	939	1070	0.88
Female	767	639	1.20
Unknown	18	15	1.20
Total	1724	1724	1.00

Figure 4.4 compares the age distribution of turning drivers and through drivers and Figure 4.5 gives the ratio for each age. It is apparent that both very young (16-17 year old) and old drivers are more likely to be turning than through drivers. This is consistent with the difficulty involved in making a right turn whereby those who are inexperienced (the very young) and those with diminished capacity (the old) are more likely to be involved.

Figure 4.4
Comparing turning and through driver age for
Adelaide signalised intersection fail to stand right turn casualty crashes 1998-2002

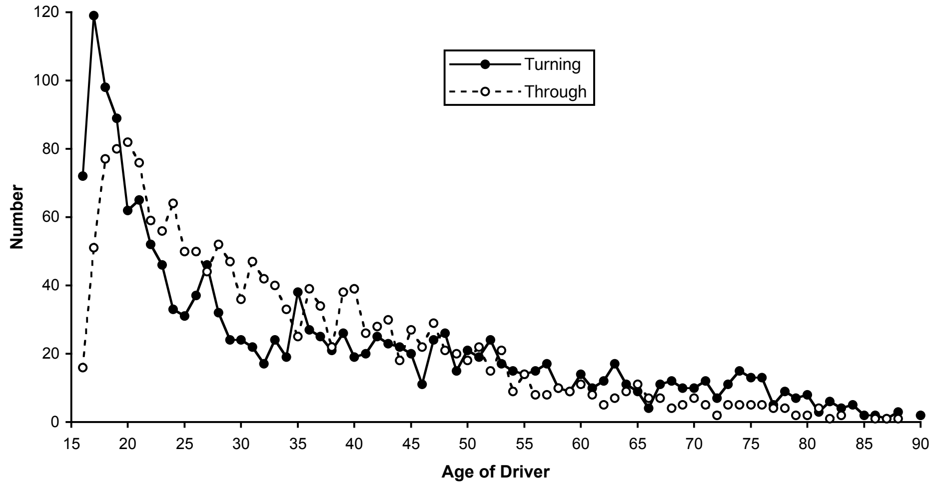
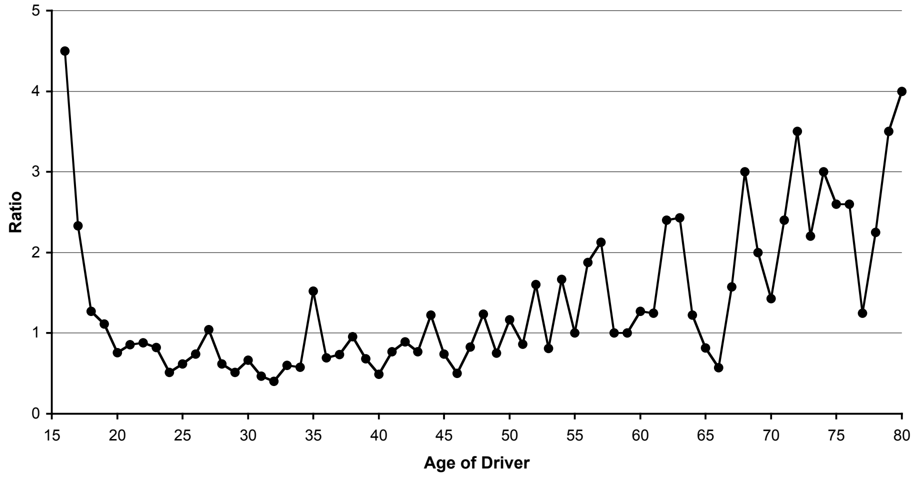


Figure 4.5
The ratio of turning to through drivers by age for
Adelaide signalised intersection fail to stand right turn casualty crashes 1998-2002



5 South Australian crashes of all severities

Analysis of the Traffic Accident Reporting System (TARS) database was undertaken to characterise Adelaide metropolitan signalised intersection crashes of all severities and in particular, right turn crashes at these intersections.

5.1 Crash selection

TARS data for the years 1981 to 2002 were used to obtain an historical overview and data for the years 1998 to 2002 were analysed in detail. The following sequential selections were made:

- All reported crashes of any severity in South Australia between 1998 and 2002 (in practice this means all crashes reported to the police where someone was injured in the crash or the resultant damage to property was $1,000 or greater)
- Selected only those crashes occurring within the Adelaide statistical division
- Selected only those crashes occurring at an intersection
- Selected only those intersections controlled by traffic signals
- Selected only those crashes classified as right turn crashes
- Selected only those crashes where the crash error was “fail to stand”
- Selected only those crashes with exactly one turning vehicle and exactly one vehicle proceeding straight ahead (this enabled the characteristics of the turning and straight through vehicles to be compared which is not possible in the TARS database where there are multiple vehicles executing the same manoeuvre since vehicle contacts are not recorded)

Table 5.1 shows the number of crashes at each stage of the selection process and their proportions of all crashes in South Australia and the Adelaide metropolitan area.

Table 5.1
Crash selection process
South Australia 1998-2002

Selection Process	Number	Per Cent of all SA Crashes	Per Cent of all Adelaide Crashes
All SA reported crashes	203184	100.0	-
Crash in Adelaide statistical division	169077	83.2	100.0
Crash at intersection	84025	41.4	49.7
Intersection controlled by traffic signals	39156	19.3	23.2
Right turn crash	6442	3.2	3.8
Fail to stand crash	5896	2.9	3.5
Identifiable vehicles	5779	2.8	3.4

5.2 Adelaide signalised intersection crashes

Table 5.2 shows the types of crashes occurring at Adelaide signalised intersections. While rear end crashes form the single largest group, right turn crashes form the next largest accounting for nearly 17 per cent of crashes at Adelaide signalised intersections.

Table 5.2
Crash types at Adelaide signalised intersections 1998-2002

Crash Type	Number	Per Cent
Rear End	22478	57.4
Right Turn	6442	16.5
Right Angle	4159	10.6
Side Swipe	3937	10.1
Hit Fixed Object	1109	2.8
Hit Pedestrian	378	1.0
Head On	234	0.6
Hit Parked Vehicle	193	0.5
Other	129	0.3
Roll Over	67	0.2
Left Road Out of Control	14	0.0
Hit Object on Road	11	0.0
Hit Animal	5	0.0
Total	39156	100.0

5.3 Adelaide signalised intersection right turn crashes

Table 5.3 shows the police assigned crash error for right turn crashes at Adelaide signalised intersections. By far the most common error was fail to stand which is of primary interest in this report as there is very little that can be done about drivers who disobey traffic signals. The other crash errors do not apply to a normal right turn crash and the seven cases observed may be due to errors in coding or exceptional circumstances. They are excluded from this point on.

Table 5.3
Crash error in right turn crashes
at Adelaide signalised intersections 1998-2002

Crash Error	Number	Per Cent
Fail to stand	5896	91.5
Disobey - traffic signals	539	8.4
Fail to give way	5	0.1
No errors	1	0.0
Dangerous driving	1	0.0
Total	6442	100.0

5.4 Adelaide signalised intersection fail to stand right turn crashes

Table 5.4 shows the crash injury severity of fail to stand right turn crashes at Adelaide signalised intersections and compares the distribution with that for all Adelaide crashes. It is apparent that such right turn casualty crashes tend to be more severe than Adelaide casualty crashes in general.

Table 5.4
Severity of signalised intersection fail to stand right turn crashes
compared to all crashes in Adelaide 1998-2002

Crash Injury Severity	Number	Per Cent	All Adelaide crashes (%)
PDO	4112	69.7	82.7
Private Doctor	397	6.7	7.2
Hospital Treated	1175	19.9	7.9
Hospital Admitted	209	3.5	2.0
Fatal	3	0.1	0.2
Total	5896	100.0	100.0

Figure 5.1 compares the number of right turn crashes over time with all Adelaide crashes as a percentage of the 1981 numbers (no figures are available for 1982 or 1993). Since 1991, it appears that right turn crashes have been rising at a greater rate. We do not know why this is the case but it may be related to factors such as: an increase in the number of signalised intersections; greater volumes of traffic through signalised intersections; changes in the control of right turns at signalised intersections; and changes in the coding practices that identify right turn crashes in the TARS database.

Figure 5.1
Change in Adelaide signalised intersection fail to stand right turn crash numbers
over time compared to changes in all Adelaide crash numbers

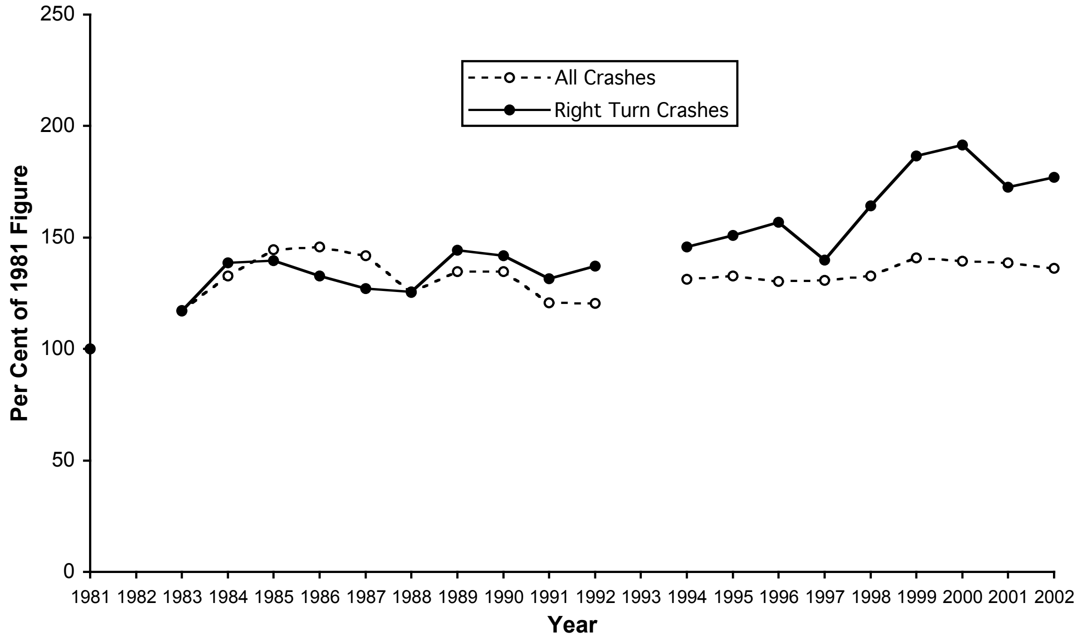


Figure 5.2 compares the distribution of right turn crashes by hour of day with that for all Adelaide crashes. While the right turn crash distribution has similar peaks to that for all crashes, the peaks are not as pronounced and the evening peak extends later into the evening. We do not know the reasons for these differences but they may be related to: some elimination of right turns at peak hours; a greater proportion of drivers not undertaking right turns at peak hours; and traffic congestion creating safe gaps for right filter turns at peak hours.

Figure 5.2
Hour of day of Adelaide signalised intersection fail to stand right turn crashes compared to all Adelaide crashes 1998-2002

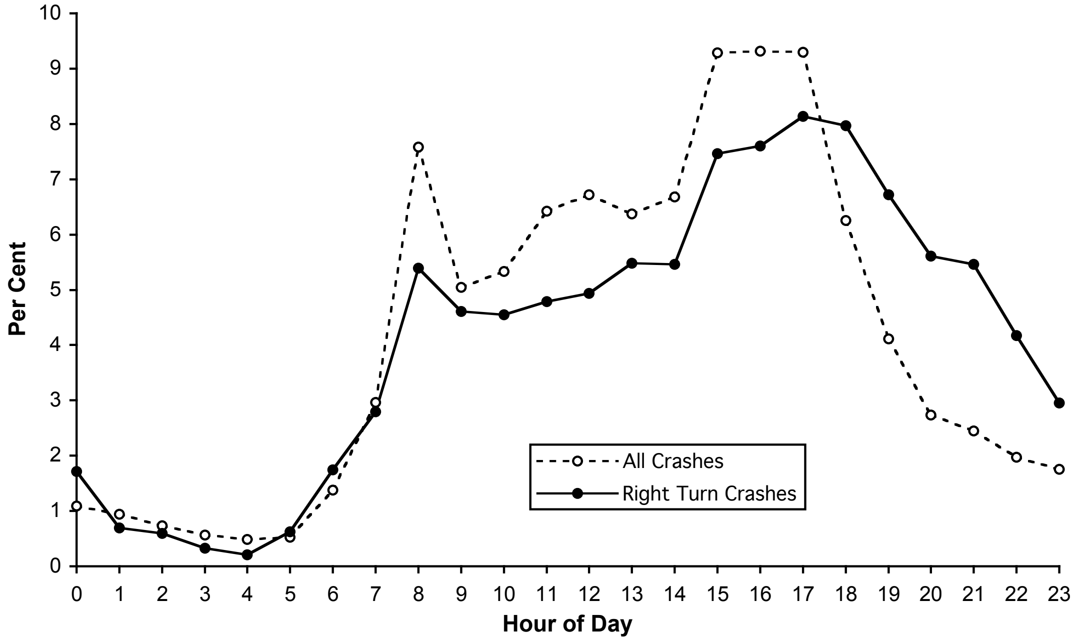
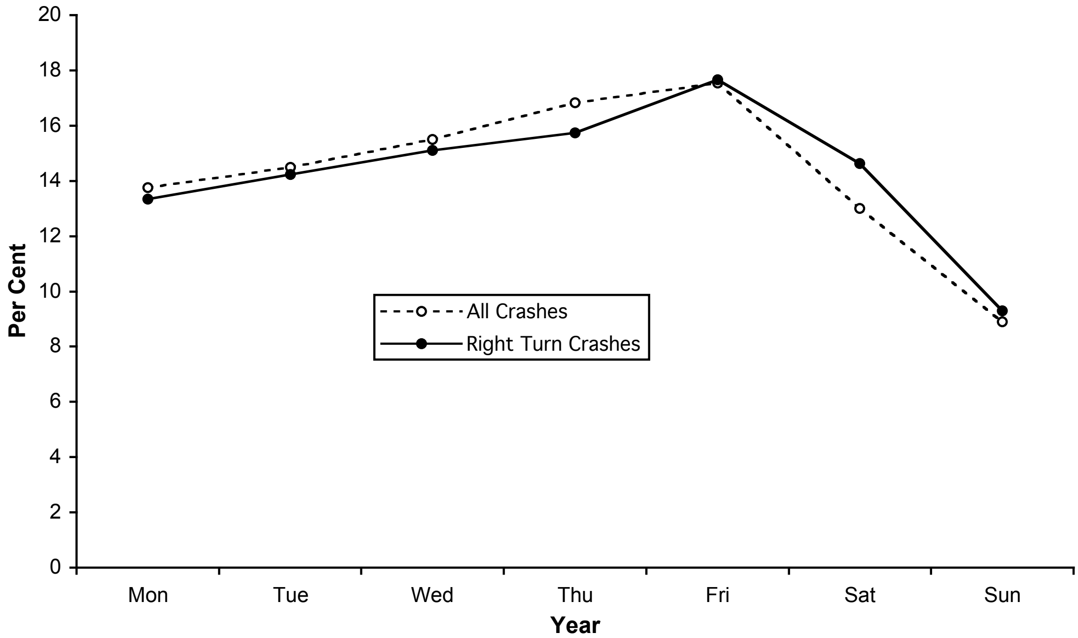


Figure 5.3 compares the distribution of right turn crashes by day of week with that for all Adelaide crashes. Both distributions are very similar with rates generally rising through the week and dropping on the weekend.

Figure 5.3
Day of week of Adelaide signalised intersection fail to stand right turn crashes compared to all Adelaide crashes 1998-2002



5.5 Comparing turning and through vehicles and drivers

It is instructive to compare aspects of the turning vehicle with the through vehicle. However, due to limitations in the way that the TARS database is coded, these vehicles cannot be identified when there are more than two vehicles involved. Therefore, for the following analyses, only those crashes with exactly one turning vehicle and exactly one vehicle proceeding straight ahead were selected. This amounts to 5779 out of the 5896 fail to stand right turn crashes (98.0%).

Table 5.5 shows the types of turning and through vehicles involved in the right turn crashes. By dividing the number of turning vehicles of a given type by the number of through vehicles of a given type we get a ratio. If the ratio is greater than 1 then that type of vehicle is more likely to be a turning vehicle than a through vehicle and conversely if the ratio is less than 1 then that type of vehicle is more likely to be a through vehicle than a turning vehicle.

Table 5.5
Comparing turning and through vehicle types for
Adelaide signalised intersection fail to stand right turn crashes 1998-2002

Type	Turning (A)	Through (B)	Ratio (A/B)
Car	4391	4221	1.04
Station Wagon	695	718	0.97
Semi Trailer	21	22	0.95
Utility	160	169	0.95
Truck	43	49	0.88
Taxi Cab	67	81	0.83
Panel Van	142	176	0.81
Omnibus	14	27	0.52
Motor Cycle	22	89	0.25
Pedal Cycle	11	64	0.17
Other/Unknown	213	163	-
Total	5779	5779	1.00

Cars appear slightly more likely to be turning vehicles while buses, motorcycles and pedal cycles are substantially more likely to be through vehicles. The motorcycles and pedal cycles are probably over represented as through vehicles since they are smaller vehicles which are harder for the driver of a turning vehicle to see. Buses and to a lesser extent trucks may have trouble slowing for signal changes and may have a lower exposure to right turns without traffic signal assistance.

Table 5.6 compares the ratio of being a turning driver compared to a through driver by the sex of the driver. There is a clear distinction whereby females are more likely to be turning drivers and males are more likely to be through drivers ($\chi^2 = 74.53$, $p < 0.001$). We do not know the reason for this difference but it may be related to: males having a better spatial sense than females for picking gaps; males being more likely to speed through an intersection especially on a yellow or red light; and females being more likely to take right turns than males.

Table 5.6
Comparing turning and through driver sex for
Adelaide signalised intersection fail to stand right turn crashes 1998-2002

Type	Turning (A)	Through (B)	Ratio (A/B)
Male	3250	3753	0.87
Female	2363	1952	1.21
Unknown	166	74	2.24
Total	5779	5779	1.00

Figure 5.4 compares the age distribution of turning drivers and through drivers and Figure 5.5 gives the ratio for each age. It is apparent that both very young (16-17 year old) and old drivers are more likely to be turning than through drivers. This is consistent with the difficulty involved in making a right turn whereby those who are inexperienced (the very young) and those with diminished capacity (the old) are more likely to be involved.

Figure 5.4
Comparing turning and through driver age for
Adelaide signalised intersection fail to stand right turn crashes 1998-2002

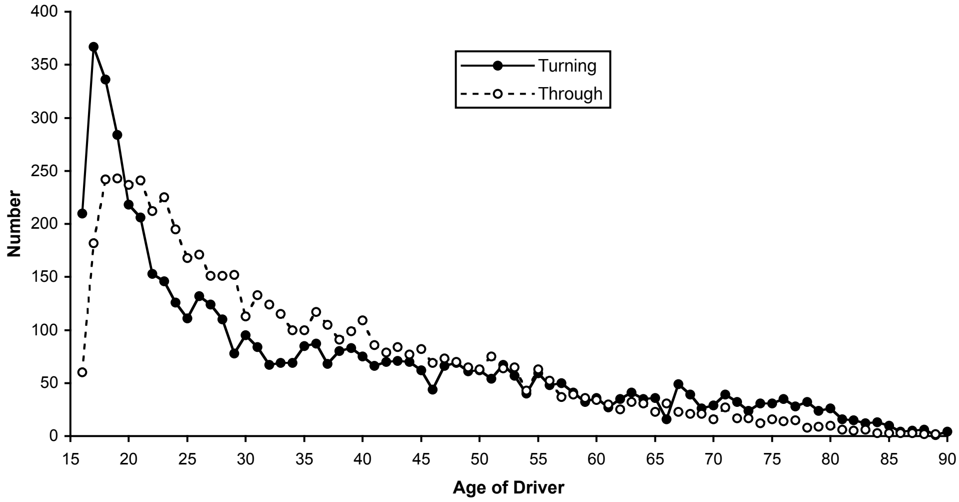
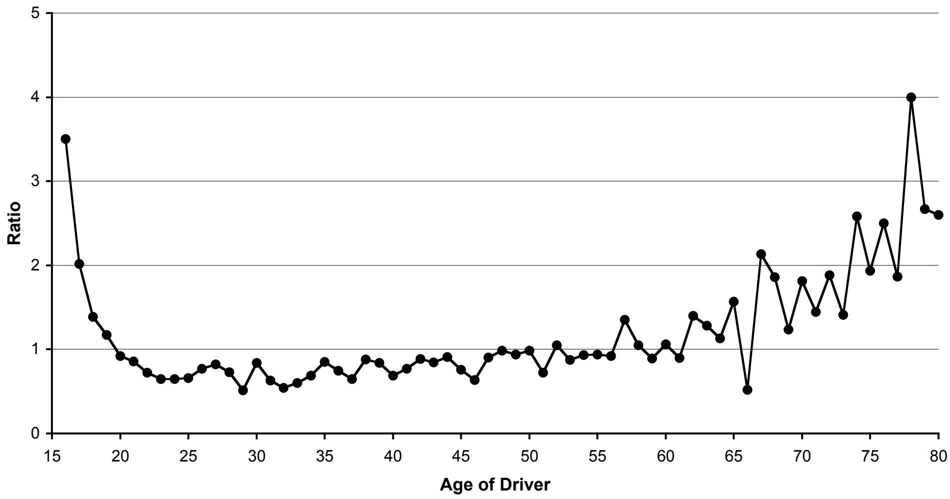


Figure 5.5
The ratio of turning to through drivers by age for
Adelaide signalised intersection fail to stand right turn crashes 1998-2002



6 In-depth crash investigation

An in-depth study of casualty crashes in the Adelaide metropolitan area was conducted by the Road Accident Research Unit of Adelaide University for a case-control study of the relationship between travelling speed and the risk of involvement in a casualty crash (Kloeden, McLean, Moore and Ponte, 1997).

While this sample of crashes is not representative of Adelaide crashes as a whole, the subset of crashes at signalised intersections is of particular interest since speeds of the through vehicles were calculated in each case.

Out of the 148 crashes investigated, 38 involved collisions at signalised intersections. Six of these 38 collisions involved a driver who had entered the intersection against the signal. All of the remaining 32 collisions involved a collision between a vehicle that was turning right and an oncoming vehicle that was proceeding straight through the intersection. The resulting collisions were severe, with one quarter of them resulting in at least one person being admitted to hospital and, in one case, being fatally injured. (It should be noted that one criterion for a crash to be included in this sample was that at least one person had to be transported to hospital.)

Over 90% of these signalised intersections had red and green arrows to control right turns but, as far as could be determined, almost all of the collisions occurred when the arrows were no longer illuminated and through traffic still had a green signal. At least one driver stated that she became confused when the red right turn arrow was turned off but the green signal for through traffic remained on. She assumed that it meant that it was safe to turn, only to be confronted with oncoming traffic that still had a green signal. This effect may be a factor in why right turn crash rates at partially controlled intersections appear to be little different from uncontrolled intersections (see Section 2.2.2).

There was some indication that elderly drivers, over 70 years of age, were particularly likely to be involved as the turning driver in this type of crash compared with those who were travelling straight through the intersection. The percentages in these two groups were 23% and 3%, respectively. Young drivers, under 21 years of age, were over-represented in both groups: 32% and 26%, respectively.

Thirteen of these 32 collisions involved a car travelling faster than 70 km/h through the intersection in a 60 km/h speed limit zone.

7 Summary of findings

This Section summarises the findings of the previous Sections.

7.1 Problem size

Right turn crashes at Adelaide signalised intersections:

- average around 1290 crashes per year
- account for 3.2% of crashes in South Australia
- account for 3.8% of crashes in Adelaide
- account for 16.5% of crashes at Adelaide signalised intersections
- are mostly judged by the Police to be due to the right turning vehicle failing to stand (91.5%)
- appear to have been increasing in number since 1993

Right turn casualty crashes at Adelaide signalised intersections:

- average around 390 casualty crashes per year (which costs the South Australian community around $27 million per year)
- account for 5.2% of casualty crashes in South Australia
- account for 6.7% of casualty crashes in Adelaide
- account for 26.9% of casualty crashes at Adelaide signalised intersections
- are mostly judged by the Police to be due to the right turning vehicle failing to stand (91.3%)
- appear to have been increasing rapidly in number since 1993

Right turn fatal crashes at Adelaide signalised intersections:

- average around 2 fatal crashes per year
- account for 1.5% of fatal crashes in South Australia
- account for 3.5% of fatal crashes in Adelaide

7.2 Older drivers

The literature review identified older drivers as being particularly at risk of making errors when turning right at a signalised intersection. The analysis of the Adelaide crash data bore this finding out as does intuitive reasoning. Older drivers tend to have diminished visual perception, cognitive processing speed, and psychomotor skills, leading to more errors when undertaking the difficult right filter turn manoeuvre.

7.3 Young drivers

The analysis of the South Australian data found that young drivers (16-17 years of age) appear to have a particularly high risk of crashing while turning right at a signalised intersection. This can primarily be attributed to some combination of inexperience and adolescent risk taking behaviour.

7.4 Road engineering

The literature indicates that very large safety benefits can be derived by controlling right turns at intersections through the use of turning arrows which eliminate the difficult judgements involved in making a filter turn.

The use of partially controlled right turns where the turning arrows are only used for part of the turning cycle appears to be little better than no turning arrows at all (although this conclusion is based on a single study, it was a well designed study).

The practice of turning off right turn arrows at peak times due to increased traffic flow amounts to removing the protection when it is most needed.

There is also some evidence that dedicated right turn lanes which reduce rear end crashes may also reduce right turn crashes possibly by reducing the pressure on drivers to make a right turn earlier than they feel comfortable doing so.

However, these countermeasures for reducing right turn crashes at signalised intersections will also reduce the efficiency of traffic flowing through the intersections. While this issue is beyond the scope of this report, it will need to be considered if these countermeasures are to be implemented.

7.5 Vehicle monitoring

It is unclear from the literature that the use of red light cameras at controlled intersections reduces right turn crashes although they do seem to increase the overall safety at such intersections.

While right turn crashes at intersections where no traffic signal was disobeyed are invariably blamed on the turning driver, there are indications from the analysis of Adelaide fatal and injury crashes that there may also be fault on the part of the through drivers. Specifically, through drivers involved in such crashes are more likely to be travelling above the speed limit and faster than through vehicles in general. These higher speeds make the task of deciding when it is safe to turn more difficult for the turning driver and make crash and injury avoidance less likely once drivers realise a collision may be about to occur. The newer red light cameras have the built in ability to detect speed violations as well as red light violations and may provide a means to reduce right turn crashes at signalised intersections.

Acknowledgements

This study was funded by the South Australian Department for Transport, Energy and Infrastructure (DTEI) through a Project Grant to the Centre for Automotive Safety Research. The DTEI Project Manager was Michael White.

The Centre for Automotive Safety Research receives core funding from both DTEI and the South Australian Motor Accident Commission.

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

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