Severe and Fatal Car Crashes Due to Roadside Hazards

A report to the

Motor Accident Commission

by

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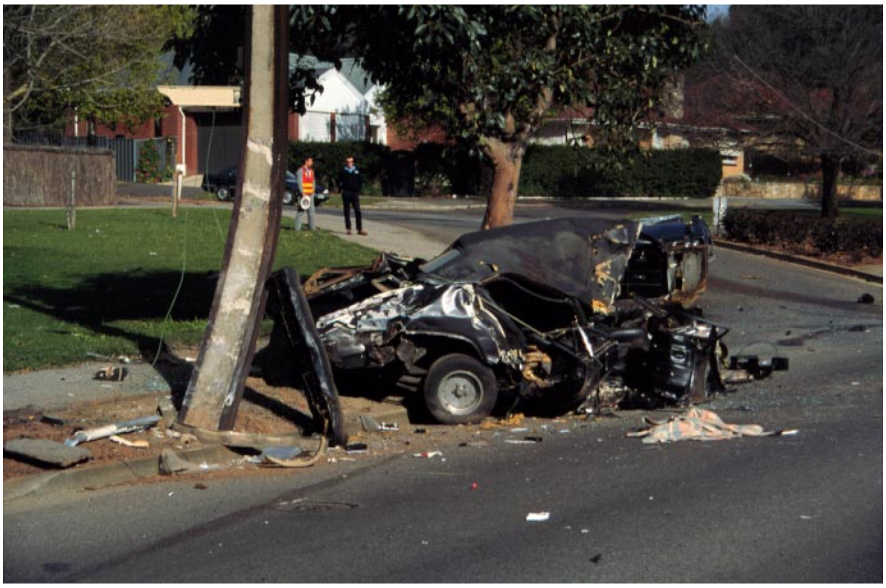

Final Report - May 1999

SUPPORTING
THE DRIVE TO
SAVE LIVES

EXECUTIVE SUMMARY

The NHMRC Road Accident Research Unit (RARU) was funded by the Motor Accident Commission in 1997 to investigate the role of roadside hazards in road accidents resulting in death or serious injury to a car occupant in South Australia.

The main aim of this project was to document the extent to which roadside hazards contribute to severe and fatal car crashes in South Australia and to comment on the opportunities that exist to make our roadsides safer.

A secondary aim of the project was to conduct investigations in such a way as to provide for the training of engineers from Transport SA in the recognition of hazardous roadside features and an appreciation of their importance in road safety.

The study was based on information contained in the Traffic Accident Reporting System data base on road accidents reported to or by the Police and on information in Coronial records of fatal crashes. Some roadside hazard crashes were also investigated at the scene.

We found that:

Roadside hazards were the immediate cause of at least one death in 40 per cent of all crashes in which a car occupant was fatally injured in South Australia from 1985 to 1996.

Collisions with roadside hazards were the immediate cause of 39 per cent of all car occupant deaths during those years.

Roadside hazards also played a role in 38 per cent of all car crashes in which an occupant was admitted to hospital in South Australia from 1994 to 1996.

Countermeasures aimed at reducing travelling speed, drink driving, and driver fatigue are likely to decrease the frequency of roadside hazard crashes, probably to a greater degree than crashes in general. However, reliance on attempts to change driver behaviour alone will not be an adequate response to the dangers presented by roadside hazards.

There is much that can be done to further improve the safety of our roads and roadsides.

Cars that ran onto the unsealed shoulder of the road were 20 per cent more likely to be involved in a fatal collision with a roadside hazard than were cars involved in other types of crash in which an occupant was fatally injured. Sealing part of the shoulder of the road and providing edge lining reduces the risk of a driver running off the road, particularly on curves.

The potential benefits of clear zones alongside roads are evident in this study. More than half of the fatal hazards in the crashes in this study were within 3 metres of the edge of the road, partly reflecting the number of crashes involving poles and trees in urban areas. Overall, 90 per cent of the roadside hazards which were struck by a car, fatally injuring at least one occupant, were located less than 9 metres from the edge of the roadway.

Trees were by far the most common roadside hazard in South Australia, accounting for 23 per cent of all deaths to car occupants and being involved in 17 per cent of all serious injury crashes. Some of the fatal crashes were with trees which had been planted by the then Highways Department in what are should be clear zones.

Collisions with Stobie poles accounted for an average of about 10 deaths and 70 hospital admissions per year in South Australia.

Sixty five car occupants were fatally injured when their car either rolled down a steep embankment, ran into a drain, or struck the face of a cutting. Many of these deaths could have been prevented by either changes to the earthworks alongside the road or the provision of guard rails.

Although cases in which a guard rail performed as intended did not appear in the fatal accident data files, there were 13 car occupants who were fatally injured when their car hit a guard rail. These fatal cases show that further investigation and refinement of the design and installation of guard rails is warranted.

Six car occupants who died in collisions with fences on the boundaries of private property were impaled by the top rail of the fence. Many similar fences which were erected by the Highways Department adjacent to signalised pedestrian crossings in the Adelaide area have yet to be replaced, even though at least one has been a direct cause of fatal injury to a car occupant.

This study has shown that the investigation and monitoring of the causes and consequences of road crashes in South Australia is hampered by the inadequacies of the main source of data, the Traffic Accident Reporting System.

RECOMMENDATIONS

Current levels of enforcement of legislation relating to speed and drink driving be maintained or increased.

Consideration be given to the elimination of 110 km/h zones in rural areas of South Australia and to a reduction in the speed limit to 50 km/h on all roads in urban areas.

The horizontal alignment of the road, the condition of the road surface, and the provision of sealed shoulders and edge lines be subject to timely review, initially on all State and National Highways in South Australia, and a case be made for the provision of funds to permit early rectification of such deficiencies as may be identified.

As soon as practicable, shoulders be sealed to a width of at least half a metre on all highways and major roads in South Australia, commencing with curved sections of road, and despite standard traffic engineering practice, edge lining be provided on highways and major roads in South Australia regardless of the width of the road.

The roadside tree planting policies of Transport SA and local government authorities be reviewed taking into account current best road safety practice to prevent new planting in hazardous locations and to rectify the dangers posed by trees which have been planted within 9 metres of rural roads. In urban areas a clear zone should be maintained within a minimum of 1 metre from the edge of the road and preferably 3 metres or more wherever practicable.

A standing committee similar to the NSW Hazardous Pole Program Committee be convened to identify and implement all practicable ways of reducing the deaths and injuries resulting from collisions with Stobie poles.

Casualty crashes with guard rails be the subject of detailed investigation, supplemented by the investigation of cases that can be identified in which a guard rail has performed as intended.

A review be conducted of recent developments in the design of guard rails, including a French design which is constructed from softwood logs and is widely used on minor rural roads in that country.

The system of reporting on road accidents in South Australia be reviewed with reference to the systems operating elsewhere, including the United States.

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1. INTRODUCTION

1.1 Initiation of this Project

The NHMRC Road Accident Research Unit (RARU) was funded by the Motor Accident Commission in 1997 to investigate the role of roadside hazards in road accidents resulting in death or serious injury to a car occupant in South Australia.

1.2 Aims of this Project

Drivers sometimes leave the roadway unintentionally for various reasons. For example, they may have fallen asleep, been intoxicated, or have lost control as a result of an unanticipated event on the roadway itself. Whatever the reason for the off-road excursion, the penalty should not be death or serious injury to the occupants of the car. Regrettably that is often what happens.

The main aim of this project was to document the extent to which roadside hazards contribute to severe and fatal car crashes in South Australia and to comment on the opportunities that exist to make our roadsides safer. By identifying the nature and extent of specific roadside hazards this report also provides a factual basis for decisions relating to the allocation of funds for known and practicable countermeasures.

A secondary aim of the project was to conduct investigations in such a way as to provide for the training of engineers from Transport SA in the recognition of hazardous roadside features and an appreciation of their importance in road safety.

1.3 Scope of this Project

The problem of roadside hazards in crashes is a complex issue like road accidents themselves. In order to try and tackle the problem of understanding roadside hazards better, a four pronged approach was used as detailed below.

1.3.1 Literature Review

A detailed review was carried out of the literature from previous studies of the role of roadside hazards in car crashes and relevant countermeasures.

1.3.2 Car Crashes and Roadside Hazards in South Australia

In order to get a broad picture of the role of roadside hazards in car crashes of all severities, information from the police traffic accident reporting system database was obtained and analysed. The information in this database is drawn from the police accident report forms and the actual role of roadside hazards in the crash is not always clear. However, although it could be improved, it is the best available collection of data on all reported road crashes in South Australia and it does give some indication of the overall involvement of roadside hazards in crashes of all severities.

1.3.3 Fatal Car Crashes and Roadside Hazards in South Australia

The Coroner’s records of crashes in which a car occupant was fatally injured in South Australia for an 11 year period were obtained. They were reviewed in detail with specific emphasis on the role of roadside hazards in causing the death of occupants of cars and light commercial vehicles. The usually detailed information available in these files enabled the role of roadside hazards in fatal crashes to be studied in as much detail as possible without a dedicated team actually attending road crash scenes.

1.3.4 At Scene Investigation of Roadside Hazard Crashes

While analysis of the police database and Coroner's files as described above gives relatively objective statistical data about the role of roadside hazards in road crashes, it cannot fully convey the harsh reality of severe crashes involving roadside hazards. In order to give the reader of this report a better feel for what happens when a car crashes into a fixed object, a number of actual cases that have been investigated by RARU staff are used to illustrate particular topics.

This part of the project also provided for the training of engineers from Transport SA in the recognition of hazardous roadside features and an appreciation of their importance in road safety.

2. LITERATURE REVIEW

A number of literature databases were searched for material and the advice of other experts in the road safety field was sought to identify other relevant publications.

2.1 Definition of a Roadside Hazard

The term “roadside hazard” refers to any fixed object by the side of the road that, by virtue of its structure and placement, results in, or is likely to result in, an increased probability of vehicle damage, occupant injury or fatality in the event of a motor vehicle leaving the roadway. Such hazardous fixed objects include trees, utility poles, luminaire supports, sign posts, bridge rails and end treatments, fences, embankments and cuttings, ditches, guard rails (and guard rail end treatments), mail boxes and drainage structures (culverts, for example).

2.2 The Extent of the Problem

It is difficult to give an assessment of the extent of the problem of roadside hazards based on the available literature due to the fact that most authors are concerned with specific hazards rather than roadside hazards generally. Also most authors describe the extent of the problem within a limited geographical boundary. Nonetheless, the literature is unanimous in claiming that roadside hazards play a substantial role in both fatal and injurious road crashes. The following is a summary of studies detailing the extent of roadside hazard crashes, which in turn is summarised in Table 2.1.

Sabey and Taylor (1980) considered environmental features to be a factor in about 30 per cent of road crashes in the UK. Lawson (1985) reported that single vehicle collisions with roadside objects accounted for 55 out of 173 (or approximately 32%) of all non-pedestrian fatal crashes in the West Midlands of England in a period of 2 years in the early 1980s. The same author reported a study conducted between the start of 1980 and the end of 1982 on 13 radial routes in Birmingham. Of 3818 injury accidents, 260 were single vehicle crashes involving an impact with a roadside hazard (Lawson, 1985). More recently, Proctor (1996) reported that for all of Great Britain in 1994, there were 18,585 injury crashes with roadside objects.

Nilsson and Wenall (1998) reported that in Sweden each year, 9,000 roadside objects are struck by errant vehicles and that these collisions account for 25 per cent of road fatalities.

In the Province of British Columbia in Canada, it was found in 1991 that vehicles running off the road accounted for 16.9 per cent of all highway crashes, resulting in an estimated societal cost of $70m (de Leur, Abdelwahab & Navin, 1994)

Tignor, Brinkman, Mason and Mounce (1982) reported that in 1980 in the US, 40 per cent of fatal crashes occurred off the roadway. This combination of roadside hazard crashes and rollovers equated to 21,531 fatalities.

Mak and Mason (1981) reported that fixed object crashes account for 11.7 per cent of all crashes in the US, while Kedjidjian (1993) stated that of all US highway crashes resulting in a fatality, 62 per cent involved a single vehicle and 30 per cent involved an impact with a fixed roadside object. Ray, Troxel and Carney (1991) reported that one third of all crashes in the US involve a feature of the roadside and that this equates to 900,000 occupants per year being involved in fixed object collisions, leaving 9,000 dead. When only side impacts with roadside objects are considered, each year in the US, 225,000 occupants are involved in such crashes, leaving one in three injured and one in a hundred dead (Ray, Carney, Faranawi & Troxel, 1994). This annual injury level produces a societal cost of three thousand million dollars (FHWA, 1988) and these collisions comprise a quarter of those contained within both the National Accident Sampling System and the Fatal Accident Reporting System (Ray & Carney, 1995).

In a study in Victoria, Australia, 23 per cent of all serious casualties were found to be related to roadside hazards, with 1,454 dead or seriously injured in 1994, the most common objects struck being trees, poles and embankments (Corben, Deary, Mullan & Dyte, 1997).

Similar data emerged from a study into road crashes in rural Victoria between 1978 and 1982. Run-off-the-road crashes accounted for 35 per cent of those crashes producing casualties. Sixty-two per cent of these involved a fixed roadside object and thus, 22 per cent of all rural casualty crashes were roadside hazard crashes. This amounted to 420 fatal and 3,930 casualty crashes involving roadside hazards (Sanderson & Fildes, 1984).

Table 2.1 summarises the extent of roadside hazard crashes as reported in the literature review above. Attempts have been made to report statistics in a form enabling comparison across the different studies but in many instances this has not been possible.

Table 2.1
The Extent of Roadside Hazard Crashes as Reported in the Literature

Author(s)	**Location**	**Extent of Roadside Hazard Crashes**
Lawson	West Midlands, UK, 1980-1982	32% of fatal
Lawson	Birmingham, 1980-1982	7% of injury crashes
Proctor	Great Britain, 1994	18,585 casualty
Nilsson &Wenall	Sweden	25% of fatal
de Leur et al	British Columbia, Canada, highways, 1991	16.9% of highway crashes
Tignor et al (1982)	US, 1980	20,000 fatalities (40%)
Mak & Mason	US, 1976	11.7% of all crashes
Kedjidjian	US highways, 1991	30% fatal
Ray, Troxel & Carney	US, 1980-1985	33% of all crashes
Corben et al	Victoria, 1994	23% of casualty
Sanderson & Fildes	rural Victoria, 1978-1982	22% of casualty

Thus, roadside obstacles are recognised by all authors as posing substantial risks to road users in the event of their vehicles leaving the roadway. To deal with the problem of roadside objects, there are a number of broad categories of treatments available. These possible solutions include (a) removal of the hazard, (b) relocation of the hazard to a place where it is less likely to be struck, (c) qualitative improvement of the hazard so that it is less likely to cause a fatality or injury in the event of being struck, or (d) construction of an impact attenuation or redirectional device to guard against unimprovable hazards (Nairn & partners, 1987). Which treatments are chosen will depend on several factors such as the general location of the hazard, economic factors (the choice of treatment could, for example, depend on the outcome of investigations such as cost benefit analyses), and the type of hazard involved.

The importance of this last factor in determining which treatments are necessary to reduce the trauma resulting from collisions with roadside objects is reflected in the tendency of authors to focus their respective attentions on only one of the various hazards. By far the most researched and discussed roadside object in the literature is the pole, whether it be a utility pole carrying overhead conductors or a luminaire support (referred to hereafter by the more prosaic term “light pole”). The next Section discusses the research conducted on the role of poles in road crashes and what can be done to minimise this role in future. A summary of the studies reporting the extent of pole crashes is provided in Table 2.2.

2.3 Poles

2.3.1 The Extent of Crashes Involving Poles

A study by Pilkington (1988) found that 14.4 per cent of roadside object crashes in the US involved poles and it was added that this number would serve as an underestimate of the true extent of such crashes due to a sizeable percentage of pole accidents not being reported to police. This number of pole crashes equates to a rate of 0.12 pole crashes per mile of roadway per year. It was found that the rural and urban pole crash rates were the same, with these crashes involving 34 per 100 million vehicles passing in both settings. Pole crashes were 6 times more likely than other crashes to lead to a fatality and 3 times more likely to lead to an injury. Drivers were more frequently injured whilst passengers were more likely to sustain fatal injuries. Eighty per cent were frontal impacts and the remaining 20 per cent were side impacts, with the latter more commonly producing a fatality.

Jones and Baum (1978) also conducted a study into pole crashes in the US, focusing on urban settings. Police reports nationwide for 1975 included 8,000 pole crashes. Poles were the most frequently struck roadside object (21.1%), comprising 2.2 per cent of all crashes. These crashes, more importantly, featured the highest injury rate (50.5%) for all crashes, excepting rollovers (52.6%).

Another US study was conducted by Mak and Mason (1981), looking at both urban and rural crashes. Poles were among the most frequently struck roadside objects, accounting for 28.4 per cent of roadside hazard crashes and 3.3 per cent of all crashes. These authors also reported a high rate of injuries and fatalities for pole crashes with 1.2 per cent causing a fatality (6.2 times more likely than the average crash) and 43.4 per cent causing injuries (3 times more likely).

In another study, Tignor, Brinkman, Mason and Mounce (1982) stated that in 1981 in the US, impacts with poles accounted for 12 per cent of fatal run off the road crashes. This percentage equated with approximately 1,550 crashes that resulted in a fatality. Only trees were struck more often (Tignor et al, 1982).

When just side impacts are considered, pole crashes have also been found to feature very highly in US statistics, with utility poles accounting for 21 per cent of side impact fixed object crashes and 25 per cent of fatalities. Light poles accounted for 10 per cent of side impacts and 10 per cent of those resulting in a fatality. The fatality rate for side impacts with light supports was found to be double that for frontal impacts. Thus, when poles of all descriptions are considered, poles crashes were found to comprise nearly one third of fatalities involving side impacts with roadside hazards (Ray, Troxel & Carney, 1991).

Huntington (1997) conducted a study of pole crashes in Christchurch, New Zealand. It was found that during the years from 1990 to 1994 inclusive, there were 941 pole crashes (6 per cent of all crashes in that period). Thus, there were approximately 188 pole crashes per year and one pole crash per 8.4 km of roadway per year. Of these, 22 were fatal crashes with 26 lives lost. This equates to a rate of 1 in 43 crashes being fatal, compared to a rate of 1 in 113 for all crashes. This level of trauma produced a cost over the 5 years of $219m.

Nilsson and Wenall (1998) stated that in Sweden there are around 2,000 crashes with poles reported each year to the police. These crashes on average kill just over 20 motorists per year. This number represents approximately 10 per cent of single vehicle fatalities in 1994 and 12 per cent of those in 1995.

A study conducted in Sydney (Piper, 1985) concentrating on urban roads found that over half of the objects impacted were poles and that pole crashes were 1.6 times more likely to lead to injuries compared to other roadside hazard crashes. Another study in New South Wales (Energy Authority, 1989) reported that each year in that state, there are 100 fatalities and 2,000 injuries resulting from collisions with poles. In rural Victoria between 1978 and 1982, there were 20 fatalities and 211 casualties resulting from impacts with poles (Sanderson & Fildes, 1984).

A study by Good, Fox and Joubert (1987) conducted in the 1970s in Victoria estimated that there are 45 deaths and 785 injuries in Melbourne every year due to pole crashes. This accounts for 9.4 per cent of Melbourne road deaths and 5.9 per cent of Melbourne road injuries. Referring to data from the Victorian Road Safety and Traffic Authority, the authors reported that pole crashes comprise 45 per cent of fixed object crash fatalities and 52 per cent of fixed object crash injuries. For all of Victoria, pole crashes resulted in 54 deaths (5.8%) and 813 injuries (4.6%). The severity of pole accidents, in terms of the number of fatalities per 100 casualty accidents, is 1.5 times the severity of the average metropolitan road crash. Most injuries to occupants were to the head, neck and upper torso, although frontal impacts with poles also resulted in abdominal injuries.

Another study in Victoria conducted by Haworth, Vulcan, Bowland and Pronk (1997) looked at 127 fatal single vehicle crashes between December 1995 and November 1996 that occurred within 200km of Melbourne. In the metropolitan area, 33 per cent of fatal single vehicle crashes involved poles. The rural figure was 12 per cent giving an overall proportion of 25 per cent of fatal single vehicle crashes featuring impacts with poles.

In Adelaide, the problem of pole crashes is compounded by the types of poles that line many of the city's streets. So called "Stobie poles", numbering 600,000 in South Australia, are constructed of two rolled steel joists separated by concrete. Built for durability, they are unforgiving in the event of a car colliding with them. Attention has regularly been drawn to the problem of Stobie poles in the past (eg McLean, 1994) and most recently in articles in *The Advertiser* (25/10/1998, p18; 10/10/1997, p16), which quoted Office of Road Safety figures showing that in Adelaide in the past 16 years, Stobie poles have been involved in 112 fatal crashes, 3,226 injury crashes and 5,241 property damage crashes.

Table 2.2 summarises the extent of pole crashes as reported in the literature review above. As with Table 2.1, attempts have been made to report statistics in a form enabling comparison across the different studies but in many instances this has not been possible.

Table 2.2
The Extent of Pole Crashes as Reported in the Literature

Author(s)	**Location**	**Extent of Pole Crashes**
Pilkington	US highways, 1985	14.4% of RH
Jones & Baum	US urban, 1975	21.2% of RH
Mak & Mason	US, 1976	28.7% of RH
Tignor et al	US, 1981	1,550 fatals
Ray, Troxel & Carney	US side impacts, 1980-1985	21% of RH
Huntington	Christchurch, NZ, 1990-1994	941 crashes, 6% of all crashes
Nilsson & Wenall	Sweden	2,000 crashes, 20 fatals per year
Piper	Sydney, NSW, 1983-84	over 50% of RH
Energy Authority	NSW	100 fatalities per year
Sanderson & Fildes	Victoria, rural, 1978-1982	20 fatalities, 211 casualties
Good, Fox & Joubert	Melbourne, Victoria, 1976-1978	45% of RH fatalities
Haworth et al	Victoria, 1996	25% of fatal single vehicle

NB: RH stands for roadside hazard crashes

Thus, the literature reveals that poles, whether they be utility poles or light poles, are a common contributor to the casualty and fatality rate for the occupants of cars that leave the roadway. In particular, it is recognised that pole crashes involve a substantially higher level of injury severity than the average road crash and, for this reason, dealing with the problem of poles must be an integral part of any road safety program aimed at reducing the risks posed by roadside hazards.

The following Section looks at attempts to treat the problem of pole crashes. Firstly, consideration is given to the strategy of replacing rigid poles with breakaway poles and secondly, other suggested and previously implemented treatments are discussed.

2.3.2 Breakaway Poles

One commonly suggested countermeasure (eg Nilsson & Wenall, 1998; Huntington, 1997; Energy Authority, 1989; Good, Fox & Joubert, 1987) to reduce the severity of crashes into poles is to install breakaway poles in the place of more rigid ones. When a vehicle impacts with a rigid pole, the concentrated impact results in substantial damage to the vehicle and injury to the occupants. The idea behind breakaway poles is that when a vehicle collides with one, the pole breaks, allowing the vehicle to continue on its path, having experienced a markedly lower change in velocity and degree of damage than would be experienced with a rigid pole. This means that there is a far smaller risk of damage to the car and injury to the occupants and the car can be brought to a stop through the process of braking rather than a sudden impact.

There are a number of different designs for poles that collapse on impact. The most commonly used breakaway pole and that reported to be the best by Tignor et al (1982) is the slip base pole. Slip base poles are designed such that when impacted, the pole shears off and detaches from its base and rotates about its inertial axis away from the vehicle. This allows the vehicle to pass under the pole with a minimal change in velocity (Ray & Carney, 1995). Such poles were originally used to support street lighting but have more recently been used in place of rigid utility poles (Kedjidjian, 1993). As is the case with breakaway light poles, a slip base at the bottom of the pole gives way on impact. The difference is that breakaway utility poles need to be constructed so that the utility lines do not fall down. This is accomplished by an upper hinge that allows the pole to bend and by cables near the top of the pole that support the lines.

Another form of breakaway pole is the Enquist-Svenson-Vanke pole which was designed in Sweden in the late 1970s and which brings a colliding vehicle to a stop by slowly absorbing the energy of the impact. The cross section of the pole, when impacted, is flattened and energy is absorbed by the deformation of the pole. The flattened pole is first pulled around the vehicle’s bumper before starting to wrap around the rest of the vehicle. As it is further flattened, the energy of the crash is gradually being absorbed, allowing the vehicle to come to a comparatively slow rather than a sudden stop (Ray and Carney, 1995). However, a significant problem with ESV poles is that after each impact, the pole is destroyed, resulting in high repair or replacement costs (Tignor et al, 1982).

As the technology of breakaway poles has been in existence for some time, it has been possible for evaluations to have been made of their performance in real world situations. For example, a study by Mak and Mason (1981) in the US found that crashes with breakaway poles were significantly less injurious than those with rigid poles. Wooden utility poles produced a fatal to severe crash rate of 7.4 per cent compared to 3.8 per cent for breakaway poles. This reduction in the severity of crashes with breakaway poles was attributed to a low change in velocity on impact even at high impact speeds.

Kurucz (1984) studied 609 single vehicle crashes in Florida to determine the effects of breakaway poles and seat belt use on the relationship between injuries and impact severity as measured by squared impact speed. It was found that the effects of these two variables were dependent on impact severity, with greater impact severity resulting in higher effectiveness of breakaway poles and seat belt use in reducing the probability of moderate or greater injury. Further, it was found that the reduction in injury resulting from breakaway poles as compared with rigid ones was greater than the reduction resulting from seat belt use. Kurucz (1984) suggested that if all of the rigid poles in the area were replaced by breakaway poles, there would be one sixth the number of serious injuries resulting from impacts with poles. In cases where the driver was not wearing a seat belt, impacts at a speed of 88 km/h with a rigid pole would produce a serious injury rate of 65 per cent compared to 11 per cent for a breakaway pole, assuming the lack of any additional significant impacts. These results were generally consistent with those of Mak and Mason (1981) although the injury severity reported in Mak and Mason was lower due to the rigid poles in that study being made of aluminium or wood, whilst those in the study by Kurucz (1984) were constructed from concrete and steel.

A study conducted in Sydney (Energy Authority, 1989) looked at the casualty crash reduction resulting from a variety of countermeasures. Of those considered, the use of slip base light poles in conjunction with increased lateral offset of the poles (moving the poles further from the edge of the road) and undergrounding of services, was found to be the best. The casualty crash reduction rates that were calculated for the use of slip base poles in conjunction with increased lateral offset (with the lateral offset of the poles included in brackets) were 72 per cent (1 m), 78 per cent (1.5 m), 84 per cent (2 m), 87 per cent (2.5 m) and 93 per cent (3 m).

Kedjidjian (1993) also reported that field studies of breakaway poles had yielded promising results. Initial evaluations of breakaway utility poles revealed that there had been no fatalities or serious injuries in collisions with them. Similarly, Ray and Carney (1995) stated that in Scandinavia, there had been no fatalities resulting from impacts with the Enquist-Svenson-Vanke pole after a decade of use, with the occupant impact response in frontal collisions being found to be well below the threshold of serious injury. The authors, however, failed to provide a baseline for crashes in Scandinavia against which to compare the lack of fatalities for the ESV pole.

Ivey and Morgan (1986) found substantial reductions in injury levels with the use of slip base utility poles. At an impact speed of 100 km/h, 76.5 per cent of crashes with rigid utility poles resulted in serious injuries to one or more of the occupants. With a breakaway utility pole, the level of serious injury for such crashes was found to be 0.5 per cent. The levels of serious injury for an impact speed of 60 km/h were 22.4 per cent for the rigid pole and 0.6 per cent for the breakaway pole, and for 30 km/h, the relative figures were 2.5 and 0.4 per cent (Ivey & Morgan, 1986).

There have been, however, several questions raised concerning the use of breakaway poles. One of these is the issue of placement. First, it needs to be recognised that the full benefit of the replacement of a rigid pole with a breakaway pole will only be realised if there is a clear area beyond the pole. Breakaway poles will be less effective if placed directly in front of a rigid object such as a wall (Kedjidjian, 1993). Huntington (1997) suggested that in urban areas light weight collapsible/capture type poles would be a sensible option because they would capture impacting vehicles in a controlled manner and stop them from hitting other roadside hazards. In rural locations, however, due to the lack of pedestrians and commercial property being at risk, slip base poles could be used with ample space for the impacting vehicle to stop after the pole collision. Kedjidjian (1993) also suggested that breakaway poles are not needed on straight roads as poles, when hit, are usually hit on the outside of horizontal curves. However, most of the Stobie poles struck in Adelaide are on straight sections of road. It is also worth noting that with regard to sign posts, breakaway poles are useful for support of signs by the side of the road but not for overhead signs. If the poles supporting overhead signs broke, the sign would fall onto the roadway and pose a substantial hazard for traffic (Tignor et al, 1982).

Another question that is regularly discussed in the literature is that of whether the installation of breakaway poles will increase the likelihood of pedestrian injury. For example, Lawson (1985) reported that in 1974 in the UK, despite being advised that breakaway poles would lessen the severity of crashes, the Minister of State for Transport deemed that they could not be used in built up areas because they would result in an increased likelihood of pedestrians being struck by errant vehicles that would ordinarily be stopped by rigid poles. Lawson, however, pointed out that most single vehicle crashes with roadside objects occurred late at night when there was little pedestrian traffic. Similarly, McLean (1994) noted that claims that Stobie poles protect pedestrians can be dismissed on the grounds that in most cases when a car has struck a Stobie pole in Adelaide, the car would have, in the absence of the pole, struck a fence or gone along the footpath rather than struck a pedestrian (McLean, Offler & Sandow, 1981). Good, Fox and Joubert (1987) estimated that two thirds of cars that run off the road do not hit poles, suggesting rigid poles do not offer much protection for pedestrians. These authors also added that fewer than 1 in 200 pedestrian deaths occur off the carriageway and that pole crashes occur mostly at times and in weather when there are low pedestrian numbers.

Another issue concerning the use of breakaway poles is that of the pole causing secondary damage after being struck and knocked down. Related to this is the issue of liability. Authorities have expressed concerns about the possibility of being held liable for damages in the event of a breakaway pole causing injury after being knocked down. Lawson (1985), for example, pointed out that slipbase poles when impacted at low speeds may fall on car roofs and that breakaway poles, once struck, can cause injury to pedestrians or other motorists in secondary collisions. Kedjidjian (1993) similarly pointed to the dangers of breakaway utility poles falling into pedestrian traffic in urban areas. Good, Fox and Joubert (1987), however, reported that in a study conducted in Victoria in the 1970s, secondary collisions resulting from impacted breakaway poles were found to be insignificant when compared to the reduction in severity and cost of pole crashes. With regard to the issue of liability, Epstein and Hunter (1984) concluded that authorities would only incur liability in the event of a breakaway pole falling and causing injury if it could be demonstrated that there was carelessness in the siting of the pole. If however, authorities failed to install breakaway poles or practised a policy of continuation of rigid poles, those authorities could incur liability for injury to a motorist if it is known that the pole is in a location that is hazardous to motorists. Furthermore, Kedjidjian (1993) reported that initial studies in the US indicated a saving in liability for utility companies through the use of breakaway rather than rigid utility poles.

Ray and Carney (1995) voiced concerns regarding the performance of breakaway poles in side impacts. Side impacts with narrow roadside objects often result in head injuries because the head of the driver or passenger on the struck side impacts directly with the object. Ray and Carney pointed out that with breakaway poles, the head may hit the pole before it breaks and therefore be injured regardless of the breakaway capabilities of the pole. In a review of side impact crash tests involving small cars (Honda Civics, and Colts) and slipbase and Enquist-Svenson-Vanke poles, it was found that in most tests the occupant impact velocities with the interior of the car and the occupant accelerations were above injury thresholds. In most cases (seven tests were reviewed), there was a very high likelihood of head or thoracic trauma. The Enquist-Svenson-Vanke pole, however, did appear to perform better than slip base poles in side impacts (Ray & Carney, 1995).

The other concern to be raised is that of cost to the authorities responsible for installing the breakaway poles. Couch (1985), for example, suggested that in the case of hit and run accidents, which are possible with breakaway poles, the authorities will not be able to identify the drivers and claim the cost of replacing the pole. Kedjidjian (1993) also pointed out that breakaway utility poles are more expensive to install than rigid utility poles. However, there are benefits expected from the use of such poles with regard to better provisions of services. Pilkington (1988) claimed that breakaway utility poles are repaired in less time than standard utility poles, resulting in services being ‘out’ for a shorter period of time. Similarly, Kedjidjian (1993) claimed that the use of breakaway utility poles in the US has had no deleterious effect on telephone and electricity services due to quick restoration of poles following impacts, and further, suggested that new models of breakaway utility poles involve lower initial and maintenance costs, thus indicating that concerns over cost are not warranted.

2.3.3 Other Pole Treatments

There are a number of other approaches to the problem of pole crashes which may reduce both their frequency and severity. This Section deals with studies that consider and evaluate alternative methods for treating the pole crash problem.

A seminal work concerning pole crashes in an Australian context is summarised in Good, Fox and Joubert (1987). Conducted in Victoria, it involved a survey of 879 pole crashes that occurred in a time period of 8 months and control information obtained from a random sample of 795 sites. It aimed to produce a statistical model to generate predictions of pole crash risk on the basis of site measurements.

Good et al (1987) gave a detailed account of the nature of the pole crashes in their survey. Seventy per cent were property damage only crashes, 82 per cent were on major roads and 68 per cent were at non-intersection sites, half of these featuring horizontal curvature of the road. Almost all of the surveyed crashes were in 60 km/h zones with 8 per cent in 75 km/h, and 2 per cent in 100 km/h zones. Fifty per cent were at night and crashes were 4 times more likely in wet conditions with 38 per cent of crashes occurring in the wet. Pole crashes on curves mostly occurred on the outside of bends. Sixty-nine per cent were frontal impacts but side and oblique impacts were more severe because there was found to be a relationship between level of intrusion and injury and these impacts featured higher degrees of occupant space penetration.

Good et al (1987) analysed the crashes in terms of different types of locations: major roads, minor roads, the intersections of major roads, the intersections of minor roads and the intersections of minor and major roads. It was found that the site characteristics for 10 per cent of poles were found in 50 per cent of accident sites. The most beneficial treatment was suggested to be removal of the poles, whilst crash barriers or attenuators were claimed to be ineffective in an urban setting. Improvements to the crashworthiness of cars were described as being unfeasible but resurfacing and re-aligning the road was suggested as being good for high risk locations. The locations offering the best opportunity for remedial measures were found to be non-intersection sites on major roads. These locations produced 56 per cent of crashes and it was possible to identify a small number of sites that were responsible. It was found that isolating the poles at major intersections that required treatment was difficult but that it was possible to rank intersections according to risk.

On the basis of their analysis, Good et al (1987, p 412-413) made a number of recommendations. These included the mandatory use of breakaway or wrap-around light poles when any poles require maintenance or repair, the consideration of undergrounding conductor cables, the lateral offset to at least 3m of any poles, the removal or relocation of any poles on the outside of curves or at curve entry and exit points, a radius of more than 200m and appropriate super-elevation for horizontal road curves, maintenance of pavement skid resistance such that pendulum skid tests give a value greater than 50, and division of all four lane, two-way roads. These countermeasures, it is suggested, will lower the frequency and severity of pole crashes. The authors also pointed out that attention should be paid to the tyres of cars such that the tread depth and inflation levels of all cars equate to recommended safety levels (Good et al, 1987, p412-413).

Symons and Cleal (1982) undertook an evaluation of the predictive efficiency of Good, Fox and Joubert’s (1987) model for pole crashes. The study involved various site measurements in Melbourne and Sydney on major roads, at the intersections of major roads and the intersections of major and minor roads. The predictions of the model were then compared to accident rates at these sites for the years 1976-1980.

It was found that the model was reasonably accurate for predicting accident rates for high and low risk sites but that it was less accurate for sites deemed to be at medium risk, although the authors noted that it was possible that road and traffic conditions had changed over the five years and that such changes could in part account for discrepancies between the observed and expected accident frequencies. The best results were found for non-intersection sites whilst poor results were obtained for the intersections of major and minor roads. Meaningful site measurements for the intersections of major roads were too difficult to get. Other problems with the model include the lack of a distinction between minor and severe crashes and the extent of injuries to the occupants, the lack of an allowance for shielding (guard rails and parked cars for example), and the lack of an account of the effects of traffic engineering measures assisting roadway delineation at night (such as painted pavement marking, hazard boards, raised reflective pavement markers), which is suggested by Symons and Cleal (1982) to be important considering the prevalence of pole crashes at night. The authors also noted the existence of sharp discontinuities of gradient in the graphs relating site characteristics to risk levels resulting in great variations in risk levels for poles with only slight differences in characteristics.

Jones and Baum (1980) conducted a study in the US to determine the parameters affecting the probability and severity of a collision with a utility pole. Based on a sample of 3,270 pole crashes and 2,186 run-off-the-road non-pole single vehicle crashes, it was found that the factors determining the probability of a pole crash in order of importance were the number of poles in the immediate roadside environment (accounting for 25.7 per cent of the variance in a regression analysis), the lateral offset of the poles, the road grade, the road path and the speed limit. The factors relevant to the severity of the crashes were the stiffness of the pole and the impact speed. It must be pointed out, however, that the circumference of the pole was used as a surrogate measure for its stiffness and that the speed limit of the road was used as a surrogate measure for the impact speed. The reason for the speed limit not being as significant as a number of other factors with regard to the probability of a pole crash is that when the speed limit increases above a threshold, in this case 45 mph (72 km/h), the pole frequency decreases (ie there are greater spaces between poles). Travel speed is important, however, within an area homogenous with respect to speed limit because an increased travel speed results in a more shallow departure angle and such a trajectory is likely to expose the errant vehicle to a higher number of poles. The effect of likely departure angle may also be suggested by the finding that there was a high number of pole crashes per single vehicle run-off-the-road crashes on the right side of the road (which converts to the left hand side of the road in an Australian context) and on straight roads. These two scenarios would involve shallow departure angles (Jones & Baum, 1980).

Another study reported on the work of the Hazardous Poles Working Committee set up by the Energy Authority of New South Wales in 1982. This study (Energy Authority, 1989) sought to measure the reduction in crash rates for various countermeasures applied to pole crash "blackspots" and "blackstretches". Blackspots were defined as sections of road approximately 100m long with pole casualty crash rates of three or more in the space of five years. These spots tended to be at bend locations, associated with excessive speed or wet conditions, or near intersections associated with sudden vehicle weaving manoeuvres to avoid stopped or turning traffic or parked vehicles. Blackstretches were sections of road with substantial pole crash rates along the whole length of road rather than just at blackspots.

The most widely used countermeasure evaluated in the study was increasing the lateral offset of poles. The casualty crash reduction rates associated with relocating poles to the property line were directly related to the distance of the poles from the edge of the road. These reduction rates are as follows (with the distance from the road edge in parentheses): 13 per cent (1 m), 30 per cent (1.5 m), 50 per cent (2 m), 60 per cent (2.5 m) and 80 per cent (3 m). When this was combined with the undergrounding of services with conventional steel lighting columns moved to the property line, there was a further reduction in casualty crash rates: 25 per cent (1 m), 40 per cent (1.5 m), 57 per cent (2 m), 65 per cent (2.5 m) and 83 per cent (3 m). When instead of conventional light columns, slip base poles were used, there was further reduction again in the casualty crash rates (see Section 2.3.2 above). A protective guard rail at the kerb was found to produce a 25% reduction in crash rate (Energy Authority, 1989).

The authors submitted the results to a cost benefit analysis using the average pole crash cost suggested by Fox, Good and Joubert (1979) adjusted for the effects of inflation. It was admitted by the authors that it is problematic to apply CPI inflation rates over a long period and that injury insurance payouts have increased since the study of Fox et al (1979), suggesting the need to re-examine pole crash costs. This notwithstanding, the relationship between crash rate reductions and cost benefit ratios were calculated for the various countermeasures. It was found that to achieve a cost benefit ratio of 1, relocating poles further from the kerb would require a crash reduction of 0.5 crashes per km per year; for undergrounding cables, 2.2 crashes per km per year; for undergrounding cables with columns 2.5 m from the kerb; 1.8 crashes per km per year; and for the use of aerial bundled conductors with poles 2.5 m from the kerb, 2.1 crashes per km per year. It was also found that crash rate reductions yielding higher benefit cost ratios were approximately proportional, such that for pole relocation, a benefit cost ratio of 1 required a crash reduction of 0.5 crashes per km per year, a ratio of 2 required a reduction of 1.0, and a ratio of 3 required a reduction of 1.4 (Energy Authority, 1989).

On the basis of these results, it was suggested that sites requiring treatment be prioritised such that the first sites treated be those with the highest number of crashes. The next criterion for the selection of treated sites should be the severity of crashes taking place at the site, using a severity index with different weightings for crashes with different severity levels (eg fatal, severe injury, minor injury and property damage only) so as to differentiate between sites with the same crash rates. Finally, sites should be prioritised according to their location such that the treatment workload is likely to be shared equally among council areas (Energy Authority, 1989).

Another study reporting on the New South Wales pole treatment program was undertaken by Croft (1990). Croft reported on comparisons undertaken by Travers Morgan Pty Ltd (1990) of the frequency and severity of pole crashes between 1978 and 1983 versus those between 1983 and 1988 to determine the effectiveness of the pole treatment program in Sydney. It was found that there was an 85 per cent reduction in crash rates and in 69 per cent of cases, there were no crashes after the treatment. Before the treatment, 81 per cent of crashes caused injuries but after the treatment, only 12 per cent of pole crashes were injurious. In order to check that these differences were not due to an overall reduction in crash rates, the treated sites were compared to control sites of physical similarity and similar traffic volumes. It was found that the treated sites had experienced 75 per cent fewer crashes, suggesting that the crash frequency reduction was not due to an overall reduction in crash frequency for the city. This study also undertook an economic evaluation of the treatment program using the cost per pole crash suggested by Fox, Good and Joubert (1979) updated for inflation and including provisions for maintenance and administration costs. Cost benefit ratios for the treatments ranged between 5.6 and 8.1 (Croft, 1990).

Pilkington (1988), in an analysis of utility pole crashes in the US, reported that lateral offset of poles was a major determinant of the frequency and severity of pole crashes. In rural settings, the average lateral offset of poles involved in crashes was 2.7 m compared to the average lateral offset of 3.6 m for all poles. In urban areas, the comparison was 1.6 versus 2.0 m. Pilkington also suggested that part of the reason for the over-representation of pole crashes near intersections (within 15 m of them) is that poles are closer to the roadway at intersections than along other sections of the road. Pilkington also pointed out that there is greater frequency of poles on stretches of road with greater pole crash frequencies. In rural areas, at crash sites there is an average pole frequency of 35 poles per km versus an average rural pole frequency of 14 poles per km. In urban areas, the corresponding figures are 75 and 50 poles per km. On the basis of these findings, Pilkington recommended that an appropriate pole treatment program should include initiatives intended to increase the lateral offset of poles and to reduce pole frequency (Pilkington, 1988).

After an exhaustive study of the nature of pole crashes in Christchurch, New Zealand, Huntington (1997) concluded that the best treatment program would involve a combination of techniques dependent on the site characteristics. It was suggested that on isolated bends or curves that poles should be brightly marked to assist, in particular, drivers at night. It was added that the markers should take such a form that they are unlikely to be confused with road markers and that the colours should be different on the two different sides of the road (yellow on poles on the left side of the road and white on the right side, for example). Also suggested was that services should be undergrounded for the first 40m from an intersection. At T-junctions, any posts opposite the leg of the T should be marked and possess breakaway capabilities. The intersections of arterial roads should feature breakaway poles and the undergrounding of power and telecommunications services. Any stretch of road with a history of one crash or more per year should have its power and transmission lines underground and the poles in the centre of roundabouts should be of a breakaway nature (Huntington, 1997).

To summarise, there is a vast literature concerning the role of poles in roadside hazard crashes and alternative methods of treating the problem. From an analysis of this literature, it appears that the most likely manner in which poles should be treated is a combination of different countermeasures, including the increased usage of breakaway poles where appropriate, the lessening of the number of poles by the roadside and the increased lateral offset of poles that cannot be removed or relocated from the side of the road.

2.4 Trees

Although most attention has been paid to poles in the roadside hazard literature, the hazard that tends to be reported as being the most commonly struck is the tree. The following Section details the extent of tree crashes and a summary of the data is found in Table 2.3.

In the US, Anderson (1987) reported that of 24,401 fatal roadside hazard crashes in 1985, 2,967 (12.2%) involved collisions with trees. Tignor, Brinkman, Mason and Mounce (1982) found that 20.9 per cent of run-off-the-road fatal crashes in 1981 in the US involved trees. This percentage represented the most common form of roadside hazard crash and equated to approximately 2,700 crashes. Ziegler (1986) described the Michigan Tree Study and reported that in rural areas, tree crashes were found to be of very high severity with 11 in every 100 tree collisions being fatal. Such crashes were associated with curved roads, decreased lane widths and high levels of average annual daily traffic (Ziegler, 1986). Although rural areas are the most common sites for tree crashes, Jones and Baum (1978) reported that they are also a significant factor in urban areas with 11.1 per cent of urban single vehicle crashes involving trees.

Sanderson and Fildes (1984) conducted a study into crashes in rural areas in Victoria in the years from 1978 to 1982. Trees were found to be involved in 54 per cent of roadside hazard crashes resulting in a fatality and 47 per cent of roadside hazards resulting in a casualty. These percentages represent 229 fatalities and 1,840 casualties in the space of 5 years resulting from collisions with trees. Based on these figures, and calculating an index of the relative risk of hazards using a formula combining frequency of occurrence and level of severity, Pak-Poy and Kneebone (1988) asserted that trees are four to five times more dangerous than the next most dangerous roadside hazard, with a high frequency of occurrence and a high likelihood of a fatality in the event of a crash.

Also in Victoria, Australia, a study by Haworth, Vulcan, Bowland and Pronk (1997) looked at fatal crashes that occurred within 200 km of Melbourne in 1996. Of the 127 crashes that were investigated, 60 (47.2%) were collisions with trees. Another study conducted in rural Victoria was that by Armour, Carter, Cinquegrana and Griffith (1989) which examined 147 crashes, 110 of which involved roadside hazards. In 45.5 per cent of cases featuring a roadside object (50 crashes), the first object struck was a tree or a bush and in 35 cases it was adjudged by the authors that the tree significantly increased the severity of the crash.

In Sweden, it is reported (Nilsson & Wenall, 1998) that trees represent 50 per cent of roadside hazards struck by errant vehicles. In terms of fatalities, trees, along with culverts represent the greatest risk, with tree crashes accounting for 50 fatalities each year.

With regard to side impact crashes, Ray, Troxel & Carney (1991) report that tree crashes occur with high frequency and feature high levels of severity. Tree crashes represent 25 per cent of side impact roadside hazard crashes and produce 48 per cent of side impact roadside hazard fatalities.

Table 2.3 summarises the extent of pole crashes as reported in the literature review above. As with the two previous Tables, attempts have been made to report statistics in a form enabling comparison across the different studies but in many instances this has not been possible.

Table 2.3
The Extent of Tree Crashes as Reported in the Literature

Author(s)	Location	Extent of Tree Crashes
Anderson	US 1985	2,967 fatals, 12.2% of RH fatals
Tignor et al	US 1981	20.9% RH fatals
Jones & Baum	US, urban areas, 1975	11.1% of single vehicle
Sanderson & Fildes	rural Victoria, 1978-1982	229 fatals (54%), 1,840 casualties (47%)
Haworth et al	Victoria 1996	47.2% of fatal single vehicle crashes
Armour et al	rural Victoria, 1987-88 financial year	45.5% of RH casualties
Nilsson & Wenall	Sweden	50% RH, 50 fatals per year
Ray et al	US, side impacts 1980-1985	25% RH, 48% RH fatals

NB: RH stands for roadside hazard crashes

Approaches to reducing the frequency of tree crashes centre around removing or relocating trees from clear zones (eg Nilsson & Wenall, 1998; Pak-Poy & Kneebone, 1988). Indeed, several studies have found that many trees that are struck in casualty crashes are closer to the roadway than would be acceptable under a well-implemented clear zone policy (A full discussion of clear zones appears in Section 2.7.2). For example, Armour et al (1989) found that 89 per cent of trees struck were within 10 metres of the roadway and 54 per cent were within 5 metres. Haworth et al (1997) found that 41 of 47 trees struck were within 3 to 10 metres of the road and further, that 22 of these trees were within the Vicroads clear zone according to speed limit, annual daily traffic and road curvature (Vicroads, 1995).

Turner and Mansfield (1990), on the basis of a study of tree crashes in Alabama, USA, made a number of recommendations regarding trees and clear zones. These included the recommendation that within any clear zone, mature trees should not have a trunk diameter exceeding 10 cm. If trees are to be planted for reasons of aesthetics or erosion control, they should be placed behind barriers (such as guard rails), ditches or retaining walls. Removal of existing trees should begin with those located at crash black spots or in high risk locations such as on the outside of horizontal curves. The authors suggest that if all trees within 25 ft (approximately 8 m) of the roadway on the outside of horizontal curves, then there would be a 50 per cent reduction in collisions with trees. Although there is often opposition to tree removal programs on environmental grounds, Sanderson and Fildes (1984) point out that "safety also *must* be an important consideration." (Sanderson & Fildes, 1984, p19, original emphasis retained)

2.5 Bridges

The significance of the role of bridges in roadside hazard crashes is best illustrated by the finding that the best predictor of crash rate on a given section of road is the number of narrow bridges on the road (Hollingworth, 1983). In rural Victoria between the years of 1978 and 1982, bridges were involved in 13 fatal and 134 casualty crashes (Sanderson & Fildes, 1984).

2.5.1 The Nature of Bridge Crashes

The majority of bridge crashes (60 per cent) occur at the approach end of the bridge (Brown & Foster, 1996). They are mostly single vehicle crashes. Generally, crashes that occur at bridges with more than one vehicle involved occur for a reason unrelated to the presence of the bridge. Bridge crashes also tend to occur in rural locations (Mak & Sicking, 1994; Ogden & Howie, 1989a) despite such locations featuring a lower number of bridges and lower traffic numbers than metropolitan areas. Evans (1997) claimed that in Australia, the design standards for bridges date back to 1970 and that many bridges in rural Australia are older than that, having lower design standards and a need for upgrading. Mak & Sicking (1994) also claimed that bridges require greater design standards, suggesting that this is responsible for the over representation of trucks in crashes at the sites of old bridges. Rural crashes with bridges also tend to be severe impacts with the bridge structure.

The highest severity occurs when the collision occurs with the bridge entrance post, the lowest severity for the bridge guard rail. The reported percentage of fatalities occurring at bridges ranges between 3.5 and 14 per cent (Evans, 1997) despite the percentage of bridge crashes being in the order of 1 per cent (eg Ogden & Howie, 1989a). Bridge crashes are therefore severe in nature. Ray, Troxel and Carney (1991), in a study of side impacts, found that bridges featured the highest percentage of fatalities for crashes with broad objects, although this could have been due to some of the collisions occurring with narrow parapets and piers. Ivey, Olson, Walton, Weaver and Whitehurst Furr (1979) found that the fatality rate for bridge crashes was 56 per cent higher than for other crashes and that there were 31 per cent more fatalities and casualties at bridge sites than for other crashes. This leads to the cost of bridge crashes being high compared to those with other fixed roadside objects.

2.5.2 Risk Factors for Bridge Crashes

A number of authors have attempted to isolate the factors that increase the risk of a bridge crash. One commonly mentioned factor is the width of the bridge (Ivey et al, 1979; Gandhi, Lytton & Das, 1984; Abed-Al-Rahim & Johnston, 1993). Gandhi et al (1984) for example, suggested that a two lane bridge less than 7.2m wide is hazardous. It means that there is a very limited shoulder width which in turn means that the bridge railings are very close fixed roadside objects and in the event of loss of control of the vehicle, there is very little room allowing for control to be regained. The reaction of drivers also tends to be the hazardous one of displacing the vehicle towards the centre of the roadway. However, it appears that the more important factor, rather than just the width of the bridge taken in isolation, is the ratio between the width of the bridge and the width of the approaching road (Ivey et al, 1979; Turner, 1984; Brown & Foster, 1966). Gunnerson (1961, in Turner, 1984) reported that crash rates decrease when bridges and approaching roads are widened but that when the approach is widened and the bridge is not, there is an increase in crash frequency. Brown and Foster (1966) found that 70 per cent of bridge crashes featured a bridge to approach ratio of less than 0.79. The authors suggested that such relatively narrow bridge lanes caused drivers to collide with abutments, railings, guard rails and other traffic. Turner (1984) found that a variable created by subtracting roadway width on the bridge from the width of the bridge structure accounted for 62 per cent of the variance in bridge crash rates. The author, however, claimed that crash rates were lower in cases where the bridge was over 1.2 m more narrow than the approaching roadway and suggested that this was due to motorists recognising the hazard at such bridges and taking appropriate cautionary measures, such as reducing speed (Turner, 1984).

Another important factor in determining the risk of crashes at bridges is the road geometry, specifically the vertical and horizontal alignment of the bridge or its approach. The road geometry becomes particularly significant in bridge crashes in cases where there is a combination of a downhill approach and a horizontal curve in the road (Hilton, 1973). Ogden and Howie (1989b) reported that drivers only see horizontal alignment as a hazard but not vertical alignment. This causes drivers to slow down when driving around corners but not on crests or dips in the road.

Other relevant factors include the nature of the bridge railing. When the ends of bridge railing are unprotected, bridge crashes tend to be more severe (RACV, 1995). Rinde (1979) suggested that for bridges that carry over 200 vehicles per day, the bridge rail ends need to be protected.

Environmental conditions also play a significant role in bridge crashes. Hilton (1973) found that 50 per cent of crashes involving bridges also occurred in wet weather or when there was ice or snow on the road, compared with 31 per cent for other crashes. Mak and Sicking (1994) pointed out that darkness is also a factor in bridge crashes, with 48 per cent occurring at night, despite there being far more traffic during the day, and that in 84 per cent of cases there was no street lighting.

2.5.3 Countermeasures for Bridge Crashes

As narrowness of bridges and the discrepancy between the width of bridges and approaches are associated with an increased likelihood of a crash occurring, one countermeasure that is suggested for treating bridges is that of widening the bridge. A study by Delaney (in Berry, 1982) looked at eight bridges in Victoria that were widened. The overall reduction in crashes was 49 per cent. Hilton (1973) found widening of bridges to have the best cost benefit ratio of a number of countermeasures. Turner (1984) suggested that bridges should have a shoulder width of at least 90 cm. Zegeer and Council (1995) developed a model which showed that adding a shoulder of 60cm each side where previously there was no shoulder led to a crash reduction of 23 per cent. Smith (1982) suggested that in some cases, widening the bridge could be achieved by removing bridge railing. This, however, could only be done when there was no hazardous drop (greater than 2.7 m) at the sides of the bridge.

Another countermeasure for bridge crashes is the installation of guard rails. Zegeer and Council (1995) stated that guard rail crashes feature lower levels of severity than bridge crashes. Thus, the installation of guard rails will reduce the severity of bridge crashes, but it is important to point out that there will be an increase in crash frequency (Hilton, 1973; Brown & Foster, 1966) and it is suggested (Hilton, 1973) that such a treatment strategy is best only when widening the bridge is unfeasible. Rinde (1979) suggested that treating bridges with guard rails is only successful when the daily traffic volume is less than 2,000 vehicles a day and adds that adequate warning signs would also be necessary.

Other countermeasures, rather than treating the structure of the bridge, rely on warning drivers of the hazard (signs) or treating the road delineation (hazard markers, rumble strips).

Such countermeasures, it is suggested, will reduce the frequency of crashes but not the severity of those that occur (Evans, 1997).

In studying the effectiveness of countermeasures, Ivey et al (1979) found that structural and approach based treatments reduced both the frequency and severity of bridge crashes but Bowman and Brinkman (1988), in a review, found that studies into countermeasures were largely inconclusive. Problems with studies into the treatment of bridge crashes included different studies employing different methods of data collection (all the bridges in one location or all the bridges with a history of crashes) making it difficult to compare the effectiveness of treatment strategies across different areas featured in different studies. Other problems with studies into the effectiveness of countermeasures for bridge crashes include the failure to take adverse environmental conditions into account, the predictive capacity of models in some cases being insensitive beyond a small range, and poor coding of crashes in statistics used as the basis for the studies (Evans, 1997).

Nonetheless, it appears that bridges may be amenable to a number of treatment strategies and that consideration of the ways in which bridge structures contribute to crash frequency could lead to better planning in the construction of new bridges. For example, when new bridges are built, attention needs to be paid to the width of the bridge and the ratio of this width to the width of the approaching road. Existing bridges should also be targeted with the strategy of widening the bridge but when this is not possible, approach based countermeasures should be undertaken. Also, when there is not a hazardous drop on the side of the bridge and when there is a limited volume of traffic, bridge rails could be removed. Otherwise, to reduce the severity of crashes, guard rails could be put in place and crash cushions could be installed at bridge abutments. To achieve a viable cost benefit ratio, authorities may have to balance low cost treatment of all bridges with high cost structural treatment of a number of individual sites (Evans, 1997).

2.6 Guard Rails and Crash Cushions

One frequently suggested countermeasure for roadside hazards is the installation of guard rails and crash cushions (Lawson, 1985; Nairn & partners, 1987; Pilkington, 1988; Energy Authority, 1989; Croft, 1990, Silcock, 1996). Such devices are designed to reduce the severity of crashes when cars leave the roadway by stopping errant vehicles from impacting with unimprovable roadside objects. Due to the close proximity such structures necessarily have with the roadway and the fact that they are larger targets than point obstacles such as poles, they are roadside hazards in themselves and therefore must be designed and installed very carefully. As Pilkington (1988) noted, the presence of guard rails will create a higher frequency of crashes due to their small lateral offset but that such crashes will be less severe than those into other roadside hazards. This Section deals with the research into, and development of, guard rails and crash cushions.

2.6.1 Crashes Involving Guard Rails

In the US, impacts with guard rails comprise 10 per cent of all roadside hazard crashes (Pilkington, 1988). This percentage of crashes equates to 100,000 crashes per year (Highway Safety Directions, 1992). When side impacts are considered, Ray, Troxel and Carney (1991) reported that 9 per cent of side impact roadside hazard crashes involve guard rails, with these crashes producing 4 per cent of side impact roadside hazard fatalities. The authors suggested that this low level of severity with guard rail crashes accounts for the lower level of severity (18 per cent of crashes producing 12 per cent of fatalities) found with broad objects. The fatality rate for side impact guard rail crashes was 0.4 per cent, approximately a fifth of the fatality rate for trees (1.9%).

In the US it has been found that for impacts with the midsections of guard rails, the most serious injuries occur with high impact speeds and angles, with small vehicles and with unforgiving barriers such as strong post guard rails and rigid concrete median barriers. Of cars that impacted with guard rails in the US, 75 per cent were successfully redirected, 9 per cent overrode the barrier and 8.5 per cent snagged on the railing. Guard rails with weak posts were less likely to redirect impacting vehicles onto the roadway, the vehicle instead remaining by the roadside. It was found that when vehicles were directed back onto the roadway, there was a greater average injury severity level, regardless of whether there was a secondary collision or not (Highway Safety Directions, 1992), although it is unclear whether the authors controlled for impact speed. The highest injury rate was found for rollovers. Rollovers occurred after 9 per cent of impacts but the percentage was higher than average for guard rail end terminals (see Section 2.6.2) and for concrete barriers. In the case of concrete barriers, the percentage of cars that rolled over after impact was double that for other barriers. Smaller cars were especially prone to rollover following a collision with a concrete barrier (Highway Safety Directions, 1992).

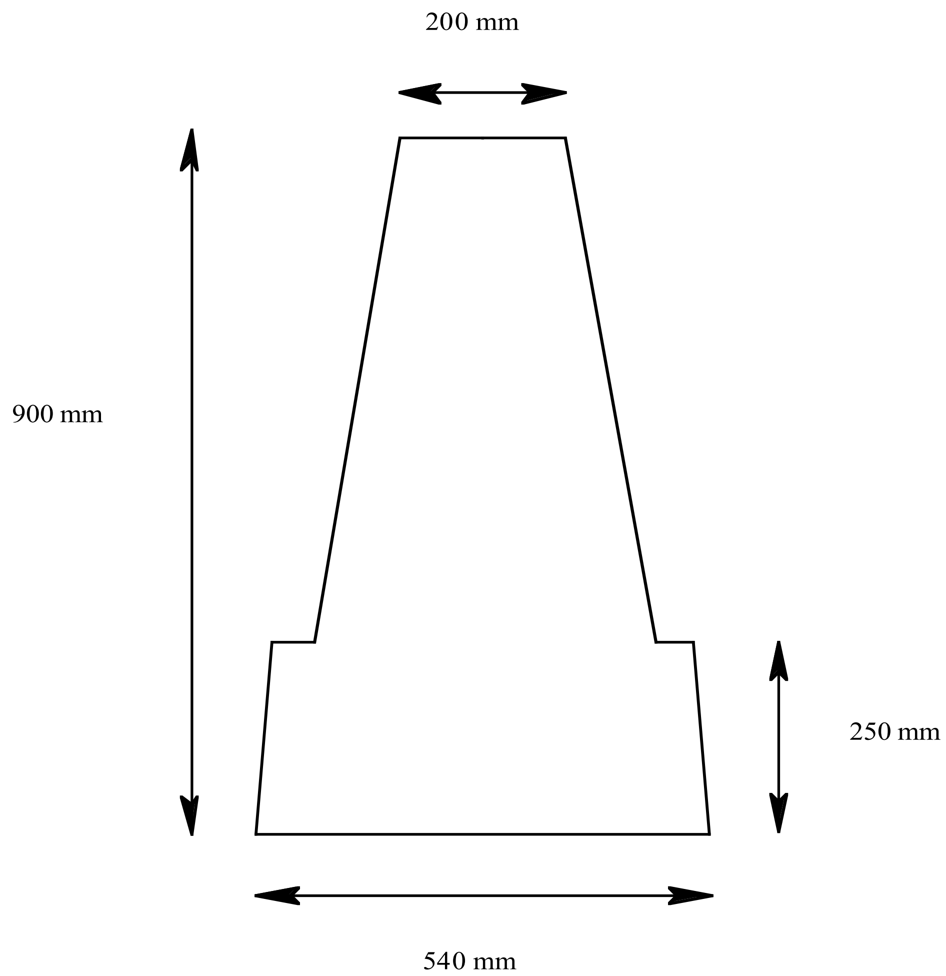
In Great Britain in 1994, there were 1,659 collisions with guard rails, accounting for 9 per cent of all roadside hazard crashes. However, when only motorways were considered, the percentage was far more substantial, with 678 guard rail crashes accounting for 57 per cent of the total (Proctor, 1996).

One study into the effectiveness of guard rails was carried out in the US by Kurucz (1984). A comparison was made between the severity of impacts with guard rails (N=76) and those with rigid objects such as utility poles, light poles, trees and piers (N=82). It was found that the effectiveness of guard rails increased (a lower level of injury compared to impacts with rigid objects) as the impact severity (defined as impact speed) increased. The probability of a serious injury was 8 times greater with a rigid object crash than a guard rail crash. It was concluded that guard rails do a good job of protecting road users from impacts with rigid objects. Although there is a higher number of impacts, there are substantially lower levels of injury severity resulting from run off the road crashes (Kurucz, 1984).

Guard rails tend to be in the form of steel fences or cables but for median barriers, authorities usually opt for concrete barriers, to prevent vehicles from veering into oncoming traffic on a high speed motorway. This is the case especially when the stretch of roadway in question features heavy traffic (the maintenance and repair of safety fences can produce a bottleneck on heavily trafficked roads) and a narrow central reservation. The most commonly used concrete barrier is the New Jersey shaped barrier. Although popular in Europe and the US, it has been found that small cars often roll over when they impact the barrier at high speed. The front wheel of the vehicle climbs up the barrier, particularly when there is a high friction level between the tyres and the concrete surface. To decrease the chance of a rollover, the slope of the barrier can be increased (made more vertical) but a larger (closer to vertical) angle leads to a higher degree of deceleration in the event of a collision and therefore a higher injury risk for non-rollovers. The trade off between the desire to minimise the risk of a rollover and the desire to minimise the rate of deceleration results in the optimum slope for concrete barriers of between 80 and 82 degrees (van der Drift & Verweij, 1996).

An additional design modification which will minimise damage in the event of a collision with a concrete barrier is the inclusion of a wider base: the STEP barrier. The STEP barrier is on an angle of 8.1 degrees and its base is 250mm high. The entire barrier is 900mm high, offering protection from the headlight glare of opposing traffic and good containment capabilities (see Figure 2.1). The top of the barrier is 200mm wide which makes it possible to be reinforced with steel and the base is 540mm wide. It comes in a number of steel and concrete versions and crash tests at speeds between 30 and 50km/h have demonstrated that damage only occurs once the impact angle reaches 15 degrees (van der Drift & Vermeij, 1996).

Figure 2.1: Dimensions of the STEP Barrier



Despite the injury reduction possible through the use of guard rails, several authors have pointed out the danger of vehicles striking the ends of guard rails, which unlike the long midsection of the rail, act as narrow objects not unlike the types of objects guard rails are installed to protect (Ray, Troxel & Carney, 1991; Highway Safety Directions, 1992; Ray & Carney, 1995; Proctor, 1996; Cornell, 1996; Schmidt, 1996). The next Section looks at the problems associated with guard rail end terminals and the attempts made to treat these problems.

2.6.2 Guard Rail End Treatments

Much effort has been put into the design of safe guard rail end terminals, producing a vast array of different types. As Cornell (1996) pointed out, end treatments fulfil two functions. The first of these is that the end must act as an anchor for the flexible barrier system. The second function of the end treatment is that it must be crashworthy. To be considered crashworthy, it must not cause spearing, vaulting or rolling of the vehicle in an end-on collision (Federal Highway Administration (FHWA), 1993). End treatments began with turned down ends of guard rails and progressed to the development of crash cushions. Crash cushions, which in the past were expensive, have been refined so that they are cheaper to make and install, and so that repair is simpler. Crash cushions have been found to be second only to seatbelts in saving car occupants' lives in the event of a crash with a fixed roadside object (Schmidt, 1996).

As mentioned above, one attempt at designing end terminals so that they did not act as rigid, narrow roadside hazards was to have the end of the guard rail tapered or turned down at the end from its standard height to the ground. Although this treatment (standard in Great Britain) stops the spearing of rails into the passenger compartments of cars, it does produce rollovers and the launching of vehicles over the railing and into protected hazards when vehicles impact the terminals at high speeds (Proctor, 1996). These ramped ends were considered dangerous enough by the FHWA (1993) for their installation and use to be prohibited along road segments featuring high traffic volume (over 6,000 vehicles per day) and high speed (80 km/h). A study by Proctor (1996) looking at collisions with barriers in Warwickshire between 1991 and 1993 found that of 110 sections of barriers struck, there were 17 collisions with a ramped end terminal. Of these, there were five cases in which the car was launched over the barrier. Despite the low probability of colliding with an end terminal, when a collision did occur, the injury severity was high. Proctor (1996) suggested that money could be saved by having continuous barriers where possible rather than small gaps which require two potentially dangerous end treatments each. Significant also was the finding that many gaps in the guard rails were less than 80m in length and that it was possible for vehicles to pass through the gaps and into protected objects. Proctor (1996) concluded that between 25 and 35 per cent of the end terminals in the Midlands were unnecessary.

Designs for end treatments have, however, advanced since the introduction of the ramped end. They may be grouped now according to whether they are gating or non-gating systems (Cornell, 1996).

2.6.3 Gating Systems

End treatments may be classified as gating systems if they include a pivot or hinge like a gate that is activated in the event of an impact and allows the colliding car to pass through. A successful gating system will allow the car to remain stable and will be installed so that the car which passes through the end terminal does not impact with the hazard being protected by the guard rail. Therefore, gating systems require clear, level terrain free of hazards behind them so that a vehicle colliding with it at high speed may come to rest safely behind the guard rail. There must be no opposite flowing traffic, no cliffs and no roadside hazards behind the gating system end terminal. The extent of the clear zone required for each type of gating system may be calculated using crash tests.

One of the first gating systems developed was the Breakaway Cable Terminal (BCT). It used wooden posts that would break away and cause the guard rail to pivot, allowing the car to pass behind the barrier. Smaller cars, however, did not activate the pivoting mechanism during crashes and so were speared on the guard rail. Thus, the manufacturers designed the Eccentric Loader Terminal (ELT) for smaller cars. The posts were weaker and a nose piece was designed to buckle the system. This design was then modified to produce the cheaper MELT and a design intended to deal with side impacts, the MELT-SI. In side impact crash tests with a Honda Civic conducted in the late 1970s, the MELT-SI was the only one of these end treatments to perform satisfactorily (Ray & Carney, 1995).

Another design is the Slotted Rail Terminal (SRT) which has been used in Victoria since 1992 but which has yet to be formally evaluated. Another, the Safe End Treatment (SENTRE) was designed so that when side impacts occur, the car is redirected into the intended traffic direction. It uses fender panels, steel posts on slip bases and sand boxes. Cars are directed away from the hard point and behind the system. Compared to the SRT and the others above, it does not require as great a clear zone, can be used near steeper slopes and 60 per cent of the system is reusable after an impact. The Transitioning End Treatment (TREND) is similar to the SENTRE but has the advantage of being able to be attached directly to fixed objects such as concrete bridge rails. It redirects vehicles away from the objects in the event of side impacts (Cornell, 1996).

The Combination Attenuating Terminal (CAT) uses slots on fender panels that shear and absorb energy. Although better than the BCT, the ELT and the MELT, it is long, expensive and even slight damage ruins the system which is non-reusable (Cornell, 1996).

The ET 2000 uses a steel assembly that slides down the rail, flattening it and curling it away from the front of the car. The danger of this system is that the steel assembly goes well beyond its original position, posing the possibility of secondary collisions. Like the BCT, ELT, MELT and the CAT, it can produce flying projectiles. Also similarly to the CAT, it will not work properly after mild damage (Cornell, 1996).

The Brifen Wire Rope Safety Fence End Terminal uses galvanised steel posts and four wire ropes. The end is designed so that the car goes behind the fence and the wires do not fly out towards the highway. The Triton Barrier uses steel reinforced, water filled plastic drums. The last section of the barrier has no water in it and this acts as the end terminal (Cornell, 1996).

Two gating systems designed to be used with concrete barriers are the ADIEM and NEAT systems. The ADIEM (Advanced Dynamic Impact Extension Module) uses soft perlite modules in a concrete base. The problem with the ADIEM is that slight damage can expose the perlite which may then erode, and wet weather may also have adverse effects on the perlite. It is yet to be evaluated in the field. The NEAT (Non-directive Energy Absorbing Terminal) system has the advantage of being able to be quickly connected to, or disconnected from, concrete barriers (Cornell, 1996).

2.6.4 Non-Gating Systems

Non-gating systems are designed to safely decelerate an errant vehicle impacting on an angle at the nose and to redirect the vehicle at other points on the barrier without allowing it to pass through. Such systems are therefore appropriate for use in medians and at locations where there is no clear, level terrain behind the barrier (Cornell, 1996).

One such system with a positive record of in-field evaluation is the Brakemaster. It is 40 per cent reusable and utilises brake cable mechanisms. Any car impacting the Brakemaster at an angle between 0 and 15 degrees is slowly captured. If the angle is greater than 25 degrees the car is redirected (Cornell, 1996).

Another non-gating system is the Guard Rail Energy Absorbing Terminal System (G-R-E-A-T System). It is comprised of cartridges of light weight polyurethane foam and steel fender panels. When a car impacts the terminal, the steel fender panels telescope back and steel diaphragms crush the foam cartridges. It is 75-80 per cent reusable even for full impacts, durable in the face of minor impacts and is easy to maintain and install. It was used to replace turned down ends in the US in 1978 and is now used in 25 countries (Cornell, 1996).

A similar crash cushion is the REACT 350 which has been installed on Mt Barker Road in the Adelaide Hills. Consisting of only four components, it is easy to install. It uses a number of high density polyurethane cylinders sitting on base tracks and held in place by steel ropes. The cylinders collapse on impact, absorbing energy, and then regain shape. Unlike single use crash cushions that not only fail to offer protection after one impact but actually become a hazard themselves, the REACT 350, post impact, still has an effectiveness rating of between 90 and 95 per cent for both head-on and side impact collisions. In addition to this, it is easily restored to 100 per cent effectiveness. It comes in three different models that may be matched to the speed limit of the road segment in which it is to be installed. For roads with speed limits up to 70 km/h, a model with one cylinder may be used. For roads with speed limits between 70 and 90 km/h, a model with six cylinders may be used and for roads with limits above 90 km/h, a model with 9 cylinders is appropriate. This high speed model, the REACT 350.9, is the only crash cushion in the world to be successfully crash tested with an impact speed of 113 km/h (Schmidt, 1996).

To summarise, guard rails provide a good means by which drivers of cars can be protected from encountering dangerous roadside hazards and terrain in the event of the car leaving the roadway. However, attention needs to be paid to the appropriateness of the type of guard rail used and the treatment of the end of the guard rail. Recent advances in crash cushion technology mean that it is possible to install relatively inexpensive and effective devices that serve to protect car occupants from serious injuries when impacting with the end of a guard rail. Again, attention needs to be paid to the environment to determine whether the end treatment should be a gating or non-gating system.

2.7 General Treatments for Roadside Hazards

2.7.1 Road and Roadside Design

Most of the literature concerning roadside hazards discusses the hazards themselves and ways in which the hazards can be made more crashworthy but some authors have looked instead at ways of treating roads and roadsides so that vehicles are less likely to run off the road into a hazard in the first place.

A study was conducted by Corben, Deery, Mullan and Dyte (1997) that sought to assess an accident black spot program that had been implemented to decrease the occurrence of crashes into roadside hazards in Victoria. The report considered 254 treatment sites and crash data from 1984-1995, a time period including equal lengths of time before and after the treatments. This data set contained 9,253 crashes: 6,989 crashes before the site treatments and 2,264 after the treatments. Overall, there had been a significant reduction of 8.6 per cent in casualty crash frequency for the treatment sites. This significant drop was mainly centred in the metropolitan area (14.5%) while treatments in rural areas had been less successful, yielding a non-significant casualty crash reduction of 4 per cent. Importantly, the most successful treatment categories were treatments of the road surface (29.6% crash reduction) and treatments of road and roadside geometry (22.9%). The most significant of road surface treatments was found to be shoulder sealing (31.8%) and the most significant treatments of road and roadside geometry were those dealing with horizontal curvature of the road (43.6%) (Corben et al, 1997).

This finding of crash reductions following the treatment of horizontal curvature of the road is consistent with the finding that roadside hazard crashes occur often with curved roads. For example, the investigation of 119 single vehicle run off the road crash sites within 200 km of Melbourne by Haworth et al (1997) found that 32 per cent of metropolitan crashes and 40 per cent of those in rural areas were on curved sections of road. Sanderson and Fildes (1984), looking at crashes in rural Victoria in the years 1978-1982, found that cars on the outside of a curve are 10.4 times more likely to have a crash and when the curved road is on a slope, all cars have 7.5 times greater likelihood of crashing. Turner and Mansfield (1990) reported that 59 per cent of urban tree crashes occurred on a curve despite there being only 5 per cent of curved road mileage in the study area. This equated to a crash ratio for curves of 12 to 1.

If side impacts only are considered, Ray et al (1991) found that 48 per cent of fatal roadside hazard crashes and 42 per cent of roadside hazard crashes overall in the US were on curves. When these figures were adjusted for the ratio of curved to straight roads, it was calculated that on straight roads, there are 29 fatal side impact roadside hazard crashes for every 100,000 driving miles (approximately 160,000km), compared to 80.5 fatalities on curved roads for the same driving distance. This adjustment also revealed the rate of side impact casualty crashes on curved roads to be over double that of straight roads (Ray et al, 1991).

The danger of curved roads has also been referred to by Nilsson and Wenall (1998), Silcock (1996), Energy Authority (1989), Pilkington (1988), Good et al (1987), Perchonok, Ranney, Baum, Morris and Epich (1978), Wright and Robertson (1976) and Hall, Burton, Copdage and Dickinson (1976). Silcock (1996) reported on a study of roadside hazard crashes in rural Scotland that found that running off the road was related to road geometry, especially horizontal curvature.

With regard to the costs of crashes, Corben et al (1997) found that the overall reduction in crash costs from the total black spot treatment program was 15.5 per cent. This is double the reduction in the number of crashes, suggesting that the treatments not only reduced the frequency, but also the severity of crashes. Again this reduction was only significant in the metropolitan area (25.4%). The reduction in crash costs for the rural area was 10.3 per cent. The most substantial crash cost savings came for road surface treatments (36.2%). When calculations of cost benefit ratios were made, it was found that the ratio for the entire treatment program was 4.1:1. Again, the metropolitan area proved more amenable to treatments, with the cost benefit ratio being 5.6:1 (Corben et al, 1997).

Corben et al (1997) concluded that best treatments for roadside hazard crashes were treatments based on road surfaces, and road and roadside geometry. They recommended an emphasis on large-scale shoulder sealing, improved horizontal road alignment and skid resistant pavements. They noted that for many different treatment types the reductions in crash frequency and costs were substantial but that small numbers meant that these treatments did not reach statistical significance. It was suggested that the rural program be enhanced, with emphasis on the treatment categories and treatment types found to be highly effective in the metropolitan area (Corben et al, 1997).

2.7.2 Clear Zones

Another method by which to reduce the frequency and severity of roadside hazard crashes is the use of clear zones on the sides of roads. Such clear zones must be free of hazardous fixed objects and feature only a mild slope to reduce the likelihood of rollovers.

Pilkington (1988) stated that on US roads 80 per cent of crashes occur within 6.1m of the roadway and that cars that have run off the road are more likely to be brought under control if the sideslope is mild (3:1) or flatter. Silcock (1996) found in Scotland that the chances of drivers recovering a car that has run off the road are related to the slope of the land and the presence, type and lateral offset of obstacles on the side of the road. Pak-Poy and Kneebone Pty Ltd (1988) reported that it is practice in the US to have a clear zone on highways extending 9m from the edge of the carriageway with a maximum slope of 6:1. This clear zone may be greater according to the curvature of the road. It is extended to 45 m on the outside of curves with a radius of 200 m (AASHTO, 1977). Such clear zones are achieved by the removal or relocation of vegetation, utility poles and street furniture such as mail boxes, telephone booths and substations. Some objects are allowed within the zone. These include light poles, traffic engineering devices such as signal and sign posts, bridges (abutments, rails, supports) and road features such as kerbs, gore structures and level crossing furniture (Pak-Poy & Kneebone Pty Ltd, 1988).

Graham and Hardwood (1982) looked at single vehicle run off the road crashes on US highways, comparing road sections with different clear zone policies (no policy; a maximum slope of 4:1; a maximum slope of 6:1). It was found that the crash rate was highest for areas without a clear zone policy and lowest where the policy stipulated a maximum slope in the clear zone of 6:1. Zegeer, Hummer, Reinfurt, Herf and Hunter (1987) looked at the relationship between clear zones and crash rates in the US. Using the term, ‘recovery distance’ for the distance between the roadway edge and the nearest slope greater than 4:1 or to the nearest roadside hazard, the authors found that when the recovery distance was increased from 3m to 5m, the crash rate fell by 17 per cent.

One study into the use of clear zones in Australia was conducted by Ogden (1996). Looking at rural roads in Victoria, Ogden found that clear zones were cost effective on rural roads even for sections of road with relatively low traffic volumes. The author recommended a 9 m clear zone policy similar to that in US for all roads with annual daily traffic of over 4,000 vehicles and a speed limit of 100 km/h. This clear zone, as well as being free of fixed roadside objects, would also have a slope no greater than 5:1 (Ogden, 1996).

2.8 Surrogate Severity Measures

Most attempts at ascertaining the risk posed by roadside hazards have been based on real world crash data. It is, however, becoming increasingly common that severity measures for roadside objects are being calculated using surrogate measures such as crash tests and computer simulation (Mak, Ross, Buth & Griffen, 1986).

2.8.1 Crash Tests

When crash tests are performed on roadside objects, researchers seek to measure the vehicle kinematics and generate estimates of the hypothetical occupant impact velocity with the interior of the vehicle and the occupant ridedown acceleration. These are then compared to recommended limits. These thresholds are given by Ray and Carney (1995) as being 9.2 m per second and an acceleration of 15 g respectively. Crash tests are also used to evaluate the structural adequacy of the object. The object must interact with a range of vehicle sizes and impact conditions in a predictable and acceptable manner. For example, objects tested must remain intact so that debris does not scatter following impact to form a traffic hazard. It is also important to consider the trajectory of the vehicle. Post impact, a vehicle may become a hazard for other traffic. It is desirable that the nature of the roadside object being tested does not increase the probability or the extent that the impacting vehicle intrudes into other lanes of the road (Miller & Carney, date unknown). Vehicles should also remain upright during and after impact and the integrity of passenger compartments should be maintained (Ray & Carney, 1995). It is also required in crash testing that unfavourable outcomes such as rollovers, vaulting, snagging and overriding barriers are noted (Mak et al, 1986).

There are, however, problems with the use of crash tests to evaluate roadside objects (Mak et al, 1986). First, the test conditions (speed, angle, car size) used in crash tests are often not representative of real world crashes. Idealised settings are used, without consideration for the environmental, geometric and cross sectional characteristics that affect crash severity. Secondly, crash tests are costly. This results in a low number of tests being performed for each different roadside object. Results tend to exhibit wide variability, suggesting that the question of repeatability is an issue. Often generalisations are made on the basis of one test under one set of conditions. Thirdly, it is difficult to relate the severity of different roadside objects because different severity measures are used for different objects. For example, tests of longitudinal barriers involve the highest 50 millisecond acceleration level, poles are tested looking at the change in velocity or momentum, and crash cushions are evaluated using a criterion based on average longitudinal acceleration. Fourthly, the objects that are tested tend to be experimental in nature rather than those in service in the field. This means that severity measures for objects in the field are unavailable (Mak et al, 1986).

The most significant of these problems is that of cost. This factor limiting the number of tests has major implications for the extent, and therefore the usefulness, of the data generated by this method. Researchers limited by having to make judgements based on only a small number of tests must generalise from examinations of crash data generated within a narrow range of test conditions. This is of particular concern given the great number of parameters affecting crash severity. These include vehicular characteristics such as the size, weight and crush characteristics of the vehicle; occupant characteristics such as the age and physiology of the occupant and restraint usage; situational characteristics such as the speed and angle of the impact; and the characteristics of the object itself such as its type (eg pole) and design (eg slip base). It is also worth noting that crash severity is not merely affected by these parameters individually but is also affected by interactions between these parameters. For example, it is possible in the case of slip base poles that crash severity would be greater with a low velocity rather than a medium velocity impact. Therefore, crash tests may be good for evaluating different designs for a given set of conditions but not for comparisons between different conditions (Mak et al, 1986).

2.8.2 Computer Simulation

Another method of estimating severity measures is the use of specially designed computer programs. These programs use the input of the impact conditions, including the characteristics of the object and the vehicle, to estimate the vehicle accelerations that occur in collisions.

There are a number of different computer reconstruction programs that are used to assess the likely severity of crashes with roadside objects. One of the most widely used roadside object computer reconstruction programs is the HVOSM. This program calculates the three-dimensional behaviour of vehicles interacting with roadside objects. It is able to reconstruct a wide variety of roadway and roadside conditions (Mak et al, 1986).

Another is the program BARRIER VII. This is a two-dimensional program for guard rail collisions used to aid the design of barriers. The vehicles simulated are simple but the guard rail is a finite element model. However, because it only models impacts in two dimensions, it is unable to predict rollovers or snagging. Such predictions can only be made when BARRIER VII is combined with RVA (Rollover Vaulting Algorithm). This latter program has been updated (RVA 2) to include modelling of the effects of shifting cargo. Programs such as GUARD and CRUNCH are three dimensional improvements on the BARRIER programs (Mak et al, 1986).

A report by de Leur, Abdelwahab and Navin (1994) details the use of the roadside hazard simulation model (RHSM) computer program to evaluate countermeasures proposed for roadside objects. The required input for the program is the trajectory of an impacting vehicle and its rollover speed, a description of any hazardous roadside terrain with reference to the degree of down slope and the friction coefficient, an inventory of any roadside objects with information on the type, size, number and location. The output of the RHSM is the probability of various degrees of crash severity (no damage, property damage only, casualty crash, fatal crash) for the particular location described in the input. This output can be used subsequently to form the basis of cost effectiveness and cost benefit analyses of a number of possible roadside hazard countermeasures such as slope modification, barrier installation and hazard removal or relocation (de Leur et al, 1994).

A study by Miller and Carney (date unknown) demonstrates that with increasing sophistication, it would be possible to replace crash tests with computer simulations. The authors report on the use of a computer program, DYNA 3D, to model high speed impacts with a crash cushion, the Narrow Connecticut Impact Attenuation System (NCAIS). The NCAIS is a complex crash cushion, featuring 8 steel cylinders and 4 cables to redirect the impacting vehicle. Despite this complexity, the DYNA 3D was capable of producing a finite element model of the crash cushion. It was found that the computer simulations of impacts with the cushion accurately reflected the results of full scale crash tests with impact velocities of 97 km/h. It is suggested by the authors that such computer programs, rather than expensive crash testing, could be used to generate measures of occupant risk (Miller & Carney, date unknown).

Mak et al (1986) agreed that severity indices would be better developed in the future from computer simulations rather than crash tests because computer programs offer greater scope for investigating a wide variety of conditions and design parameters. It is noted, however, that the models of cars and objects tend to be idealised through a series of mathematical approximations and that interactions tend to be based on assumed and simplified relationships. The authors added that, although these problems may be overcome with advances in computer technology, the programs are likely to become more complex and require greater numbers of input parameters. This will make the programs more difficult and expensive to run and increasingly prone to errors. Other problems include the difficulty in quantifying some of the parameters likely to affect crash severity and the difficulty in simulating the wide variability in the physical data of the current car fleet (Mak et al, 1986).

Mak et al (1986) concluded their discussion on computer simulations and crash tests by suggesting that more work needs to be done to link the surrogate severity measures to injury severity. To accomplish this, the damage sustained by cars in real world crashes needs to be related to the probability of injury. The damage of these real crashes can be compared to that in crash tests from which acceleration data is obtained. From this, the relationship between acceleration and injury probability can be derived (Mak et al, 1986).

2.9 Summary

The literature unanimously reports that roadside hazards play a significant role in road crashes. On average, approximately 25 per cent of road crashes involve an impact with a fixed roadside object.

One of the most commonly struck roadside objects is the pole, whether it be a light pole or utility pole. Such crashes comprising about 25-30 per cent of roadside hazard crashes and also tend to result in high injury severity. Due to the high frequency and severity of impacts with poles, the literature details a number of different treatment programs and methods for dealing with pole crashes. One of the most prevalent treatment strategies is the replacement of rigid poles with those that breakaway on impact. Such poles fracture when struck, allowing the impacting vehicle to pass through them with a much less substantial level of deceleration. This lower level of deceleration means that the impact forces on the occupants are lower, which in turn results in less injuries. Studies into the severity of pole crashes have verified this theory, finding that impacts with breakaway poles result in significantly lower injury levels. It needs to be noted that such a strategy reduces the severity, but not the frequency, of pole crashes. Treatment strategies that have been used to reduce the frequency of pole crashes include increasing the distance between poles and the edge of the roadway (the lateral offset of the poles), the undergrounding of services enabling removal of poles, and the relocation of poles away from sites where they are likely to be struck, such as on the outside of horizontally curved roads.

The most commonly struck roadside hazard is the tree. Crashes with trees also tend to be of high severity. The main method of reducing the dangers posed by trees to motorists is to implement clear zones by the side of the road. The clear zones may either be devoid of trees or at least of trees with trunks wider than a specified diameter. Alternatively, trees which are not able to be removed may be protected by guardrails, ditches or retaining walls.

Bridge crashes tend to be severe and usually involve a single vehicle crashing at the approach end of the bridge. Risk factors for bridge crashes include narrowness of the bridge, the bridge being narrower than the approach road, and the approach road featuring the combination of a downhill slope and horizontal curve. Treatments of bridges include widening of the bridge and allowing for the presence of a shoulder. If this is unfeasible, guard rails along the length of the bridge and crash cushions in front of the bridge abutments would reduce the severity of any crashes that occur. An overall treatment program that would be cost effective would be inexpensive treatment of all bridges combined with major structural treatments of bridges known to be crash black spots.

One commonly suggested treatment countermeasure for roadside hazard crashes is the use of guard rails. Due to their length and the proximity of guard rails to the edge of the roadway, their use will result in a higher frequency of crashes but impacts with guard rails are less severe than those with the roadside objects that they protect. The ends of guard rails, however, have been found to cause severe injuries when impacted and the development of treatments for guard rail ends has been the subject of much literature concerned with roadside hazards. The ends of guard rails were originally turned down but this was found to induce vaulting of impacting vehicles. Since then, guard rail end treatments have become increasingly complex. Initially expensive to install and repair, crash cushions were originally out of favour with road safety authorities but improvements to technology have seen the increasing use of crash cushions to protect the ends of guard rails. Such crash cushions are now becoming less expensive, and simpler to install, repair and maintain.

Another countermeasure for roadside hazard crashes is the treatment of the road surface and road geometry. Such treatments, including shoulder sealing and those concerning horizontal curvature of the road, have been found to reduce not only the frequency, but also the severity, of roadside hazard crashes. The usage of clear zones on the side of the roadway has also achieved desirable results. Clear zones of 9 m in which there is a mild sideslope and no fixed, rigid objects have been found to be cost effective in rural settings, including those with a low traffic volume.

Increasingly, road safety practitioners are investigating roadside hazard crashes using surrogate measures of severity. These include crash testing of roadside appurtenances and computer simulation of such crashes. In crash tests, researchers seek to measure the velocity of the occupant impacting with the interior of the vehicle and the occupants' ridedown acceleration. These are compared to theoretical tolerable limits. Also considered is the response of the vehicle, such as whether it rolled over after impact, and the response of the object being tested, such as whether it caused the scattering of potentially harmful debris. The main problem with crash tests, however, is that they are expensive and are therefore limited in number. Researchers are forced by budgetary constraints to generalise from a small data set in making their assessments regarding the severity measures of the object being tested. To overcome this, computer simulations may be utilised. The advantage of simulations is that a vast number of variations on impact conditions may be programmed into the computer to assess the performance of the object. This suggests that computer simulations will be used more often in future investigations into roadside hazards and in the development of less severe roadside objects. It must be noted, however, that there are still gaps in the data with regard to a full linkage between real world crashes, crash tests and computer simulations. It is still not possible to generate detailed estimates of injury from the forces and accelerations experienced by the hypothetical occupants of computer simulations.

3. CAR CRASHES AND ROADSIDE HAZARDS IN SOUTH AUSTRALIA

This Chapter explores the role of roadside hazards in crashes in South Australia by analysing the information recorded in police reports on road accidents for the years 1994-1996.

3.1 Source of Data

When a road accident, resulting in any injury or property damage greater than $600, occurs in South Australia, the operators of the motor vehicles involved are required to report the accident to the police. The data collected is limited to the fields on the report forms and the reliability of the information is determined by the reporting of the police, in serious cases, and the participants in the crash. In due course, the police accident report forms are forwarded to Transport SA where the information is entered into the Traffic Accident Reporting System (TARS) database.

The information on roadside hazards in the TARS database is limited, with only seven types of roadside hazard being specifically identified in the coding scheme. Also, in a particular crash, roadside hazards are only coded as being involved so it is not possible to determine which vehicles came into contact with which roadside hazards. The role that the roadside hazard played in the crash can not always be determined from the available data.

However, even with these and other important limitations, the TARS database is the best available record of road crashes ranging in severity from property damage only cases to crashes in which a road user is fatally injured in South Australia.

3.2 Method of Analysis

TARS data for the years 1994-1996 was obtained for analysis. This represented the latest three years of complete crash data available.

The TARS data file consists of three levels of information. Information on the crash is held in the crash file. Under this is the unit file which records information on each unit involved in the crash (a unit may be a vehicle, pedestrian, animal or a roadside hazard). Finally the casualty file records information on each casualty for each unit.

Since roadside hazards are coded as separate units involved in the crash there is no way to tell which vehicles actually came into contact with a particular roadside hazard. Therefore analysis had to be limited to crash based data. An extension to the TARS database that allowed interactions between vehicles and other kinds of units to be recorded would allow investigations such as the present one to be much more relevant. The categories for units that identify roadside hazards in the TARS database are: tree, traffic signal pole, bridge, sign post, Stobie pole (a concrete pole braced with steel sides), guard rail, pole, and other fixed obstruction.

Since this report deals with “car” crashes and roadside hazards, the analysed data was limited to crashes that involved a car or light commercial vehicle. The categories, as coded in the TARS database, for these units are: car sedan, car tourer, station wagon, panel van, utility, taxi, and forward control van. For convenience, these vehicles will be referred to simply as “cars” in the remainder of Chapter 3.

The injury severity of a crash was defined as the most severe injury suffered by any occupant of any car in the crash. In cases where none of these occupants was injured the severity of the crash was set to property damage only. The levels of injury used from nil to most severe are: property damage only, treated by private doctor, treated at hospital, hospital admission, and fatality.

3.3 Involvement of Roadside Hazards in Crashes

Table 3.1 shows the percentage of car crashes reported to the police in South Australia that involved a roadside hazard by the maximum severity of injury to any of the car occupants in the crash. It can be seen that as the injury severity increases, roadside hazards are more likely to be involved. The exception to this pattern is in "property damage only" crashes where a roadside hazard was slightly more likely to be involved than in a "treated by private doctor" crash.

Table 3.1
Severity of Injury to Car Occupants
in Car Crashes in South Australia 1994-1996
by Roadside Hazard Involvement

Severity of Injury	Hazard Involved %	No Hazard Involved %	Total Crashes
Fatal	48.2	51.8	280
Hospital admission	37.6	62.4	2342
Treated at hospital	24.7	75.3	6018
Treated by private doctor	7.5	92.5	5270
Nil (Property damage only)	10.5	89.5	99916
All Crashes	**11.8**	**88.2**	**113826**

The conclusion that may be drawn from Table 3.1 is that while roadside hazards are involved in a relatively small proportion of all road crashes, they are much more likely to be involved in the more serious injury outcome crashes. This will be explored in more detail below.

3.4 Incidence of Specific Roadside Hazards in Crashes

Table 3.2 shows the number of car crashes reported to the police in South Australia that involved particular roadside hazards by the maximum severity of injury to any of the car occupants in the crash. It should be noted that crashes with multiple different roadside hazards will appear in each type of roadside hazard row and that multiple roadside hazards of the same type in a crash are only counted once.

Table 3.2
Type of Roadside Hazard in Car Crashes in South Australia 1994-1996
by Severity of Injury to Car Occupants (Numbers)

Type of Roadside Hazard	Severity of Injury				
	Fatal	Hospital Admission	Treated at Hospital	Treated by Private Doctor	(Nil) Property Damage Only
Tree	83	404	544	160	2476
Stobie pole	18	203	301	52	1090
Pole	3	43	121	24	1067
Sign post	9	37	66	21	786
Guard rail	2	28	45	15	466
Traffic signal pole	-	14	37	3	247
Bridge	1	3	6	3	52
Other fixed obstruction	38	293	586	168	5300
No roadside hazards in crash	145	1461	4534	4875	89402
Total Crashes (N)	**280**	**2342**	**6018**	**5270**	**99916**

Example interpretation: 83 of the 280 crashes involving a fatality in a car also involved at least one tree in the crash.
Note: Columns may sum to greater than total number due to multiple different kinds of roadside hazards in the same crash.

Table 3.3 presents the same data as Table 3.2 but in percentage terms for each injury severity level. It can be seen that trees and Stobie poles were the most commonly struck identifiable roadside hazards at all levels of injury severity. The increase in percentage involvement of Stobie poles in hospital admissions compared to fatalities (unlike trees) is probably related to the lower travelling speeds in urban areas where Stobie poles are more common leading to less serious outcomes.

Table 3.3
Type of Roadside Hazard in Car Crashes in South Australia 1994-1996
by Severity of Injury (Percentage of column total)

Type of Roadside Hazard	Severity of Injury				
	Fatal	Hospital Admission	Treated at Hospital	Treated by Private Doctor	(Nil) Property Damage Only
Tree	29.6	17.3	9.0	3.0	2.5
Stobie pole	6.4	8.7	5.0	1.0	1.1
Pole	1.1	1.8	2.0	0.5	1.1
Sign post	3.2	1.6	1.1	0.4	0.8
Guard rail	0.7	1.2	0.7	0.3	0.5
Traffic signal pole	-	0.6	0.6	0.1	0.2
Bridge	0.4	0.1	0.1	0.1	0.1
Other fixed obstruction	13.6	12.5	9.7	3.2	5.3
No roadside hazards in crash	51.8	62.4	75.3	92.5	89.5
Total Crashes (N)	**280**	**2342**	**6018**	**5270**	**99916**

Example interpretation: 29.6% of the 280 crashes involving a fatality in a car also involved at least one tree in the crash.
Note: Columns may sum to greater than 100% due to multiple different kinds of roadside hazards in the same crash.

3.5 Estimating the Relative Danger Levels of Specific Roadside Hazards

By using row percentages of the data in Table 3.3 rather than column percentages, Table 3.4 shows the injury severity outcome given the involvement of various roadside hazards in crashes. It can be seen that crashes involving a Stobie pole were the most likely to result in an injury to a car occupant while crashes that involved no roadside hazards were the least likely to result in an injury to a car occupant. The limitation in the interpretation of this data is that it was not possible to determine whether the injuries sustained by car occupants in the crash were related to the involvement of the roadside hazard, due to the deficiencies in the file structure of the TARS database, as noted in Sections 3.1 and 3.2.

Table 3.4
Type of Roadside Hazard in Car Crashes in South Australia 1994-1996
by Severity of Injury (Row Percentages)

Type of Roadside Hazard	Severity of Injury					Total Crashes (N)
	Fatal	Hospital Admission	Treated at Hospital	Treated by Private Doctor	(Nil) Property Damage Only	
Stobie pole	1.1	12.2	18.1	3.1	65.5	**1664**
Tree	2.3	11.0	14.8	4.4	67.5	**3667**
Bridge	1.5	4.6	9.2	4.6	80.0	**65**
Traffic signal pole	0.0	4.7	12.3	1.0	82.1	**301**
Other fixed obstruction	0.6	4.6	9.2	2.6	83.0	**6385**
Guard rail	0.4	5.0	8.1	2.7	83.8	**556**
Pole	0.2	3.4	9.6	1.9	84.8	**1258**
Sign post	1.0	4.0	7.2	2.3	85.5	**919**
No roadside hazards	0.1	1.5	4.5	4.9	89.0	**100417**

Example interpretation: 2.3% of the 3667 crashes involving at least one car and at least one tree also involved at least one fatality in a car.

Table 3.5 attempts to address the problem, inherent in the structure of the TARS database, of not being able to match specific roadside hazards to specific vehicles or injuries by only considering those single vehicle crashes that involved just one car and a single type of roadside hazard. This restriction means that most of the injuries sustained in these crashes can be attributed to the car contacting the one specific type of roadside hazard. There may be cases where the particular type of roadside hazard did not cause the injuries in the vehicle, such as ejection from a rolling car which then hit a tree, so this is still an approximation of the effect of vehicles contacting roadside hazards on the injury levels of occupants. However, given the limitations of the data available, this presents a best available estimate of the injury potential of various roadside hazards.

Table 3.5
Type of Roadside Hazard in Single Car Crashes in South Australia 1994-1996 by Severity of Injury (Row Percentages)

Type of Roadside Hazard	Severity of Injury					Total Crashes (N)
	Fatal	Hospital Admission	Treated at Hospital	Treated by Private Doctor	(Nil) Property Damage Only	
Tree	2.3	11.3	14.2	4.1	68.1	2860
Stobie pole	1.0	10.8	17.2	2.5	68.5	1239
Bridge	1.8	3.5	7.0	1.8	86.0	57
Traffic signal pole	-	2.8	9.9	0.6	86.7	181
Guard rail	0.4	3.3	6.7	2.7	86.9	449
Other fixed obstruction	0.4	3.5	6.8	2.2	87.1	4522
Pole	0.2	2.3	7.5	1.2	88.7	891
Sign post	0.4	1.8	4.2	1.4	92.2	500
Total (N)	**107**	**669**	**1071**	**283**	**8626**	**10756**

Example interpretation: 2.3% of the 2860 crashes involving just one car and at least one tree (but no other types of roadside hazards or vehicles) also involved at least one fatality in the car.

It can be seen from Table 3.5 that trees appear to be the most serious of the roadside hazards that a vehicle can come into contact with. In fact, in South Australia, if a single car leaves the road and comes into contact with just a tree with sufficient force to damage the car there is a 32% chance that someone in the car will be injured and a 2.3% chance that that injury will be fatal.

Stobie poles also appear to present a similar risk of injury although the fatality rate is somewhat less than for trees. Bridges, traffic signal poles, guard rails, other fixed obstructions and poles are all a great deal less injurious although the small number of bridge crashes that did occur resulted in a rather high fatality rate. Sign posts appear to present the least danger to occupants of a striking car.

It may seem curious at first glance that Table 3.5 appears to indicate that roadside hazards are less injurious in single vehicle crashes than in all crashes as presented in Table 3.4 (since the proportion of property damage only crashes is generally greater in Table 3.5 than in Table 3.4). However, this can be explained by an artifactual effect that was part of the reason for excluding multiple vehicle crashes in the first place. Imagine a right angle collision between two cars that produces significant injuries to the occupants and that one of the cars then goes on to impact a Stobie pole with force enough to damage the car but not to further injure the occupants. Under the criteria used in Table 3.4, in such a case, the Stobie pole will be associated with a serious injury when in fact it played no part in producing that injury. Examples like this explain the apparent inconsistency and further justify the use of single vehicle, single type of hazard crashes for determining danger levels of specific roadside hazards.

3.6 Involvement of Roadside Hazards in Severe Crashes

This Section examines the roadside hazard involvement rates by selected characteristics of crashes involving a car or light commercial vehicle in which an occupant was killed or admitted to hospital. Out of the 2622 crashes matching these criteria, 1016 (38.7%) involved a roadside hazard while 1606 (61.3%) had no roadside hazard involvement recorded.

It should be emphasised that, as has previously been explained, only roadside hazard involvement in the crash (that is the roadside hazard being reported to police) is able to be ascertained. Therefore, the percentages given here are overestimates of the actual role the roadside hazards played in injuring car occupants.

3.6.1 When the Crash Occurred

Table 3.6 shows the relationship between roadside hazard involvement rates in car crashes resulting in an occupant being fatally injured or admitted to hospital in South Australia and a number of temporal variables.

Table 3.6
When Severe* Car Crashes Occurred in South Australia 1994-1996
by When Crash Occurred Roadside Hazard Involvement

When Crash Occurred	Hazard Involved %	No Hazard Involved %	Total Severe Crashes (N)
Year of Crash			
1994	36.9	63.1	830
1995	41.1	58.9	823
1996	38.4	61.6	969
Season of Crash			
Summer	38.6	61.4	599
Autumn	38.3	61.7	671
Winter	37.7	62.3	664
Spring	40.4	59.6	688
Day of Week			
Monday	35.2	64.8	267
Tuesday	30.4	69.6	276
Wednesday	39.3	60.7	303
Thursday	37.0	63.0	343
Friday	37.4	62.6	452
Saturday	42.6	57.4	495
Sunday	43.6	56.4	486
Time of Day			
12am-5am	63.7	36.3	421
6am-11am	32.9	67.1	554
12pm-5pm	28.8	71.2	923
6pm-11pm	41.4	58.6	724

* A severe crash is defined here as one in which a car occupant was fatally injured or admitted to hospital.

Both year of crash and season of crash show only minor variations in the rate of roadside hazard involvement but no real pattern. There is a definite trend towards greater roadside hazard involvement on weekends and also at night time and especially in the early hours of the morning (12am-5am) when nearly 64% of all severe crashes involved a roadside hazard.

3.6.2 Location of Crash

Table 3.7 shows the roadside hazard involvement rates in severe car crashes in South Australia in relation to the location of the crash.

Table 3.7
Location of Severe* Car Crashes in South Australia 1994-1996
by Roadside Hazard Involvement

Location of Crash	Hazard Involved %	No Hazard Involved %	Total Severe Crashes (N)
Central City	22.9	77.1	48
Adelaide metropolitan	41.6	58.4	1175
Country	36.9	63.1	1399

* A severe crash is defined here as one in which a car occupant was fatally injured or admitted to hospital.

It can be seen that while the lowest rate of roadside hazard involvement is in the central City of Adelaide, the highest rate is in the Adelaide metropolitan area. The country rate falls between these two extremes. The high density of traffic in the central City probably keeps the rate down there, while the high number of roadside objects generally in the Adelaide metropolitan area probably accounts largely for the high roadside hazard involvement rate.

3.6.3 Road Characteristics

Table 3.8 shows the roadside hazard involvement rates in severe car crashes in South Australia in relation to selected road characteristics.

Table 3.8
Road Characteristics in Severe* Car Crashes in South Australia 1994-1996
by Roadside Hazard Involvement

Road Characteristics	Hazard Involved %	No Hazard Involved %	Total Severe Crashes (N)
Type of Roadway			
Sealed	39.2	60.8	2320
Unsealed	35.4	64.6	288
Unknown	-	-	14
Speed Limit			
60 km/h	41.6	58.4	1162
80 km/h	44.1	55.9	211
100 km/h	39.9	60.1	479
110 km/h	31.8	68.2	711
Other/unknown	-	-	59
Road Condition			
Dry	37.7	62.3	2244
Wet	45.0	55.0	378
Intersection			
Intersection	22.9	77.1	933
Mid-block	47.5	52.5	1689

* A severe crash is defined here as one in which a car occupant was fatally injured or admitted to hospital.

There is no meaningful difference between sealed and unsealed roads although the comparatively small number of severe crashes on unsealed roads appear slightly less likely to involve a roadside hazard.

The speed limit of the road on which the crashes occurred shows a definite trend towards higher roadside hazard involvement rates on lower speed limit roads. This may be due to the higher density of roadside objects on lower speed roads, such as utility poles and trees.

Roadside hazard involvement is more common in severe crashes on wet roads, probably due to the greater likelihood of losing traction and leaving the roadway and thus coming into contact with a roadside object.

The rate of roadside hazard involvement is more than twice as great on mid-block sections of road compared to intersections. This is not really surprising since the potential for multiple vehicle collisions not involving a roadside hazard is obviously much greater at intersections than mid-block.

3.6.4 Number of Vehicles and Casualties

Table 3.9 shows the roadside hazard involvement rates in severe car crashes in South Australia broken down by the number of vehicles and severe or fatal casualties in the crash.

Table 3.9
Number of Vehicles and Casualties in Severe* Car Crashes in South Australia 1994-1996 by Roadside Hazard Involvement

Number of Vehicles and Casualties	**Hazard Involved %**	**No Hazard Involved %**	**Total Severe Crashes (N)**
Number of Vehicles			
Single vehicle	64.0	36.0	1408
Multiple vehicle	9.5	90.5	1214
Number of Severe Casualties			
One	40.9	59.1	1974
More than one	32.3	67.7	648

* A severe crash is defined here as one in which a car occupant was fatally injured or admitted to hospital.

As would be expected, the involvement of roadside hazards is very much greater in severe single vehicle crashes than in severe multiple vehicle crashes. What is surprising is the very high percentage (64%) of severe single vehicle crashes that involved a roadside hazard and the fact that even in multiple vehicle crashes almost 10 per cent also involved a roadside hazard.

The role of roadside hazards also appears to be greater in crashes with a single severe casualty or fatality. This is probably due to a by product of the multiple vehicle effect whereby multiple vehicle crashes are less likely to involve a hazard and more likely to involve multiple injuries due to more occupants being in the crash. Unfortunately, the TARS database does not record the number of occupants in vehicles so this cannot be investigated further.

3.7 Summary

In the road crashes involving cars that were reported to the police in South Australia in 1994, 95 and 96 it was found that:

- roadside hazards were involved in 48% of crashes in which at least one car occupant was fatally injured.
- roadside hazards were involved in 38% of car crashes in which the most severely injured car occupant was admitted to hospital.
- the most common identifiable roadside hazards were trees and Stobie poles.
- the most dangerous roadside hazards were trees and Stobie poles.

When examining only those car crashes which resulted in a car occupant being fatally injured or admitted to hospital the proportion of crashes involving roadside hazards was greatest:

- on weekends
- at night and especially after midnight
- in the Adelaide metropolitan area (excluding the central city area)
- in lower speed limit zones (due to higher density of roadside objects very close to the edge of the road in lower speed limit zones)
- on wet roads
- on mid-block sections of road
- in single vehicle crashes

4. FATAL CAR CRASHES AND ROADSIDE HAZARDS IN SOUTH AUSTRALIA

This Chapter examines in much greater detail than the previous Chapter the role of roadside hazards in the deaths of car and light commercial vehicle occupants in South Australia from 1 January 1985 to 29 November 1996.

4.1 Source of Data

Permission was received from the South Australian Coroner to copy the Coroner's files on car crashes for the years 1985-1996. These files generally contain a large amount of information on the crash including: a report by the Police Major Crash Investigators, interviews with surviving participants and witnesses, autopsy reports, blood alcohol analyses, and inquest findings.

4.2 Method of Analysis

Crashes were selected on the basis that the crash involved a fatality in a passenger car or light commercial vehicle in South Australia. A fatality was defined as death within 30 days of the crash from the injuries sustained in the crash. It was also stipulated that the driver of the car or light commercial vehicle in the crash had to be alive before the crash impact, thus excluding cases where drivers were deemed to have died of a heart attack before the crash took place.

Car and light commercial vehicles were defined as: cars, station wagons, utilities, panel vans, 4WD vehicles, passenger vans, and light trucks. For convenience, these vehicles will be referred to simply as "cars" in the remainder of Chapter 4.

A total of 1,231 crashes met the above criteria. This set of crashes contained 1,257 cars in each of which there was at least one fatality. The total number of fatalities in these cars was 1,458.

Information on the crash, the car or cars involved, the fatalities in the car/s and the roadside hazards encountered was extracted from the files and coded into a database. Individual roadside hazards were linked to particular cars and to particular fatalities to allow the role of roadside hazards to be examined on the basis of crashes, vehicles, and fatalities.

For each fatality in a car that struck a roadside hazard, a judgement was made as to whether that roadside hazard caused the death of that occupant.

A roadside hazard was judged to have fatally injured a car occupant if (in the opinion of the coders): it was struck directly by the occupant; or was the cause of the major impact imparted to the occupant via the interior of the passenger compartment, deformed or otherwise; or resulted in the occupant being ejected from the car. If the collision with the roadside hazard resulted in the car rolling over, or being redirected back onto the roadway and colliding with another vehicle, it too was judged to have caused the death of the occupant if those events were clearly related to the fatal injuries sustained.

4.3 Roadside Hazard Involvement per Crash

This Section examines crashes resulting in a car occupant being fatally injured. Any collision of a vehicle other than a car, as defined in this report, with a roadside hazard is not included.

A "fatal hazard" crash is defined as a crash where at least one fatality in at least one car in the crash was caused by the car striking a roadside hazard.

Table 4.1 shows the percentage of fatal car crashes in South Australia that involved a car occupant being killed by a roadside hazard.

Table 4.1
Roadside Hazard Involvement in All Fatal* Car Crashes in South Australia 1985-1996

	Fatal Hazard** %	Total Crashes (N)
All Fatal Car Crashes	39.8	1231

* Defined here as a fatal injury to a car occupant in the crash
** At least one car occupant fatality in the crash was caused by the car striking a hazard

4.3.1 When the Crash Occurred

Table 4.2 shows the relationship between a number of temporal variables and the percentage of fatal car crashes that involved a car occupant being killed by a roadside hazard.

Table 4.2
When Fatal* Car Crashes Occurred in South Australia 1985-1996 by Roadside Hazard Involvement

When Crash Occurred	Fatal Hazard** %	Total Crashes (N)
Year of Crash		
1985	34.1	123
1986	36.3	135
1987	39.5	129
1988	41.3	109
1989	44.0	91
1990	41.7	108
1991	38.8	98
1992	31.4	86
1993	44.4	117
1994	35.7	84
1995	47.1	85
1996	47.0	66
Season of Crash		
Summer	38.7	302
Autumn	36.4	305
Winter	43.2	271
Spring	41.1	353
Day of Week		
Monday	33.3	114
Tuesday	34.4	122
Wednesday	27.3	132
Thursday	31.6	158
Friday	40.6	202
Saturday	49.4	267
Sunday	46.6	236
Time of Day		
12am-5am	63.8	257
6am-11am	28.8	226
12pm-5pm	27.3	359
6pm-11pm	41.9	389

* Defined here as a fatal injury to a car occupant in the crash
** At least one car occupant fatality in the crash was caused by the car striking a hazard
Note that not all cases for 1994-1996 could be located and copied

Although some fluctuations in the roadside hazard crash fatality rate can be seen over the 12 year period from 1985-1996, the rate has been relatively constant over this period. Similarly, the season of the year appears to have little effect on the role of roadside hazards apart from a slight peak in the winter months.

Variations in the roadside hazard crash fatality rate were found to be strongly associated with the day of week of the crash. Much higher rates were seen on the weekend and Fridays. On Saturdays nearly half of all fatal car crashes involved a car occupant being fatally injured by a collision with a roadside hazard.

An even stronger relationship was found between the time of day that the crash occurred and the involvement of roadside hazards. Nighttime crashes were much more likely to involve a roadside hazard which fatally injured a car occupant than were daytime crashes, with the peak roadside hazard involvement rate of 64 per cent occurring after midnight.

The reasons for this time of day effect are probably related mostly to drink driving. The percentage of car drivers having a blood alcohol concentration (BAC) at or above 0.05 g/100mL was much higher in the six hours after midnight (73.4 per cent) than during the remainder of the 24 hours (31.4 per cent). Car drivers with a high BAC were much more likely to have been driving a car in which an occupant was fatally injured because of a collision with a roadside hazard (see Section 4.4.4).

Other reasons for the high rate of involvement of roadside hazards in car occupant fatal crashes at night probably include poor visibility and driver fatigue, leading to cars running off the road. Lower traffic volumes late at night would also be expected to result in single car crashes being a higher proportion of all crashes than at other times, and single car crashes almost always involve the car leaving the roadway with a consequent high risk of striking a roadside hazard.

4.3.2 Location of Crash

Table 4.3 shows the relationship between the percentage of fatal car crashes in South Australia that involved a car occupant being killed by a roadside hazard and a number of location variables.

The rate at which roadside hazards were responsible for car occupant deaths varied within each of the groupings of crash location listed in Table 4.3.

Transport SA divides the state into four regions: the Metropolitan region of Adelaide extending from Gawler to Mount Barker and Noarlunga Downs; the Mid North region including Yorke Peninsula and bounded by Port Pirie, Orroroo, Peterborough, Burra, Williamstown and including the Sturt Highway; The Eastern Region including Kangaroo Island and south from Waikerie and Renmark to the South-East of the State; and the Northern and Western region comprising the rest of the state.

Comparing the Transport SA Metropolitan Adelaide region with the rest of the state showed that fatal car crashes in that region were generally more likely to involve a fatal roadside hazard than were crashes in the rest of the state.

Comparing the four Transport SA regions showed an increasing rate of fatal roadside hazard involvement for the southern most regions with the Eastern region actually having a higher rate than even the Metropolitan Adelaide region. This is may be related to the number of roadside hazards, in particular trees, present in these areas (see Section 4.8).

In order to get a more detailed feel for specific regions of South Australia, the location of the crashes was classified into smaller regions as shown at the end of Table 4.3. The much smaller number of crashes in each region makes interpretation harder since small numbers can lead to unreliably high or low hazard involvement rates. The Adelaide area breakdown is of particular interest with the Adelaide Plains area having a low rate of hazard involvement with higher rates in the Adelaide Plains North area around Elizabeth and Gawler and the Adelaide Surrounds area in the hills and the southern beach area being greater.

Table 4.3
Location of Fatal* Car Crashes in South Australia 1985-1996
by Roadside Hazard Involvement

Location of Crash	**Fatal Hazard** %**	**Total Crashes (N)**
Metropolitan/Rural (TSA)		
Metropolitan Adelaide	43.1	529
Rural	37.3	702
Transport SA Region		
Eastern	45.8	369
Metropolitan Adelaide	43.1	529
Mid North	32.0	178
Northern & Western	23.2	155
Region		
Victor Harbor	70.0	50
Adelaide Surrounds	51.9	183
Kangaroo Island	50.0	8
York Peninsula	45.1	51
South East	44.4	259
Adelaide Plains North	42.1	190
Adelaide Plains	37.2	164
North East	34.3	35
Eyre Peninsula	28.4	74
Clare Valley	23.3	73
North	19.6	102
Sturt Highway	16.7	42

* Defined here as a fatal injury to a car occupant in the crash
** At least one car occupant fatality in the crash was caused by the car striking a hazard

4.3.3 Road Characteristics

Table 4.4 shows the relationship between a number of variables dealing with the characteristics of the road on which the crash happened and the percentage of fatal car crashes in South Australia that involved a car occupant being killed by a roadside hazard.

An examination of the type of roadway that crashes occurred on showed that local street crashes were more likely to involve a fatal roadside hazard compared to main roads and highways. Overlaid on this was a higher incidence of fatal roadside hazard crashes on Adelaide metropolitan roads leading to the greatest rate of fatal roadside hazard crashes on local Adelaide metropolitan streets and the lowest rate on main highways.

Although there was a slightly higher rate of fatal roadside hazard crashes on unsealed roads compared to sealed roads, the difference was not a meaningfully large one.

The speed limit of the road on which the crashes occurred showed a definite trend towards higher fatal roadside hazard involvement rates on lower speed limit roads. This is likely to be due to more roadside objects adjacent to lower speed roads and a higher proportion of rollover crashes not involving hazards observed on higher speed roads.

Fatal roadside hazard involvement was more common in severe crashes on wet roads, probably due to the greater likelihood of losing traction and leaving the roadway and thus coming into contact with a roadside object.

The rate of fatal roadside hazard involvement was almost five times greater on mid-block sections of road compared to intersections. This is not really surprising since the potential for multiple vehicle collisions not involving a roadside hazard is obviously much greater at intersections than mid-block.

Table 4.4
Road Characteristics in Fatal* Car Crashes in South Australia 1985-1996
by Roadside Hazard Involvement

Road Characteristics	Fatal Hazard** %	Total Crashes (N)
Type of Roadway		
Highway	33.0	573
Main Adelaide metropolitan	39.1	197
Local rural	46.5	357
Local Adelaide metropolitan	55.8	104
Road Surface		
Sealed	39.5	1107
Unsealed	42.7	124
Speed Limit		
60 km/h	46.3	326
80 km/h	39.4	109
100 km/h	39.0	141
110 km/h	37.0	646
Other	-	9
Road Condition		
Dry	38.7	1055
Wet	48.7	154
Unknown	-	22
Horizontal Alignment		
Curved	54.4	458
Straight	31.2	773
Intersection		
Intersection	10.5	314
Mid-block	49.8	917

* Defined here as a fatal injury to a car occupant in the crash
** At least one car occupant fatality in the crash was caused by the car striking a hazard

4.3.4 Number of Vehicles in the Crash

The relationship between the percentage of fatal car crashes in South Australia that involved a car occupant being killed by a roadside hazard and the number of vehicles in the crash is shown in Table 4.5. The number of vehicles in a crash was defined as the number of occupied and running motor vehicles making physical contact during the crash.

Table 4.5
Number of Vehicles in Fatal* Car Crashes in South Australia 1985-1996
by Roadside Hazard Involvement

Number of Vehicles in Crash	Fatal Hazard** %	Total Crashes (N)
Single vehicle	66.4	703
Multiple vehicle	4.4	528

* Defined here as a fatal injury to a car occupant in the crash
** At least one car occupant fatality in the crash was caused by the car striking a hazard

It can be seen in Table 4.5 that in more than 66 per cent of single car crashes involving an occupant fatality, at least one occupant in the car died as the result of a collision with a roadside hazard. In multiple vehicle crashes where most of the fatalities would be expected to be the result of the collision/s between the vehicles, only about 4 per cent of the car crashes involved an occupant being killed due to a collision with a roadside hazard.

4.4 Roadside Hazard Involvement per Vehicle

This Section is based on cars in which at least one occupant was fatally injured in a crash. A "fatal hazard" car is defined as a car in which at least one fatality resulted from it striking a roadside hazard.

A collision with a roadside hazard was the immediate cause of death in 39 per cent of cars involved in crashes in South Australia in which at least one car occupant was fatally injured (Table 4.6).

Table 4.6
Roadside Hazard Involvement for Cars in Fatal* Car Crashes in South Australia 1985-1996

	Fatal Hazard** %	Total Cars (N)
All Cars	39.0	1257

* Defined here as a fatal injury to an occupant of the car
** At least one car occupant fatality was caused by the car striking a hazard

4.4.1 Type and Age of Car

Table 4.7 shows the relationship between the body type and age of the car in which an occupant was killed and the percentage of these cars in which an occupant was fatally injured by a collision with a roadside hazard.

Table 4.7
Type and Age of Car in Fatal* Car Crashes in South Australia 1985-1996 by Roadside Hazard Involvement

Type and Age of Car	Fatal Hazard** %	Total Cars (N)
Body Type		
Sedan	42.0	919
Station Wagon	33.1	124
Light Commercial Vehicle	29.4	214
Age of Vehicle		
< 5 years	34.2	240
5-9 years	36.5	312
10-14 years	37.5	296
15-19 years	47.0	215
20+ years	45.7	140
Unknown	-	54

* Defined here as a fatal injury to an occupant of the car
** At least one car occupant fatality was caused by the car striking a hazard

It can be seen in Table 4.7 that sedan cars containing a fatally injured occupant were the most likely to have had an occupant killed by a roadside hazard and that light commercial vehicles were the least likely.

Older cars were more likely to have had an occupant fatally injured by a collision with a roadside hazard. There may, of course, be factors other than vehicle characteristics affecting this result such as the age and alcohol use of drivers of different age cars.

4.4.2 Vehicle Dynamics

The relationship between a number of variables dealing with the dynamics of the car before and during the fatal crash and the percentage of cars in which an occupant was fatally injured in a collision with a roadside hazard is shown in Table 4.8.

Table 4.8
Vehicle Dynamics in Fatal* Car Crashes in South Australia 1985-1996
by Roadside Hazard Involvement

Vehicle Dynamics	**Fatal Hazard** %	**Total Cars (N)**
Wheel Drop Off		
Yes	45.9	172
No	37.9	1085
Left Roadway		
Yes	49.5	990
No	0.0	267
Rollover		
Yes	34.1	411
No	41.4	846
Number of Other Vehicles		
None	66.4	703
One or more	4.2	554

* Defined here as a fatal injury to an occupant of the car
** At least one car occupant fatality was caused by the car striking a hazard

It can be seen from Table 4.8 that cars that dropped a left or right wheel off the side of the paved road and came back onto the road at the start of the crash sequence were more likely to continue on to collide with a roadside hazard that caused the death of an occupant of the car.

A car was defined to have left the roadway if both its left and right wheels left the roadway or would have if a roadside hazard had not been present. It can be seen that very close to half of these cars ultimately came into contact with a roadside hazard that caused the death of an occupant. Obviously, none of the cars that did not leave the roadway came into contact with any roadside hazards but it is interesting to note that of the 1257 cars in which an occupant died, 990 (79%) did leave the roadway.

A rollover was defined as a car rolling through at least 90 degrees at some time during the crash sequence. It can be seen in Table 4.8 that cars that rolled over were less likely to have encountered a fatal roadside hazard compared to cars that didn’t roll over. This effect is probably explained by cars that hit a hazard being less likely to roll and rollovers being more likely to cause a fatality without impacting a hazard.

The number of occupied and running motor vehicles that the car made physical contact with during the crash shows a marked relationship with the likelihood of contact with a fatal roadside hazard. As can be seen in Table 4.8, 66 per cent of cars involved in fatal single car crashes came into contact with a fatal roadside hazard compared to only 4 per cent of fatality carrying cars in multiple vehicle crashes.

4.4.3 Number of Occupants and Fatalities

The number of occupants and fatalities in the car that carried a car occupant who was fatally injured is related to the percentage involvement of fatal roadside hazards in fatal car crashes in Table 4.9.

Cars in which the driver was alone, or had two or more passengers were more likely to encounter a roadside hazard that caused the death of an occupant of the car compared to cars containing the driver and one passenger. Part of this effect is due to an apparent difference in the age of the driver whereby young drivers were more likely to encounter a fatal hazard when there were more people in the car and older drivers were more likely to encounter a fatal hazard when alone.

Table 4.9
Number of Occupants and Fatalities in Fatal* Car Crashes in South Australia 1985-1996 by Roadside Hazard Involvement

Number of Occupants and Fatalities	Fatal Hazard** %	Total Cars (N)
Number of Occupants		
One	42.4	540
Two	32.4	364
More than two	40.5	353
Number of Fatalities		
One	39.1	1095
More than one	38.3	162

* Defined here as a fatal injury to an occupant of the car
** At least one car occupant fatality was caused by the car striking a hazard

The number of fatalities in the car appears to be unrelated to the proportion of cars contacting a fatal roadside hazard.

4.4.4 Driver Characteristics

Male drivers were slightly more likely than female drivers to encounter a roadside hazard that caused the death of an occupant of the car but the difference is likely to have arisen by chance (Table 4.10).

Table 4.10
Driver Characteristics in Fatal* Car Crashes in South Australia 1985-1996 by Roadside Hazard Involvement

Driver Characteristics	Fatal Hazard** %	Total Cars (N)
Sex		
Male	39.9	961
Female	36.2	293
Unknown	-	3
Age		
14 – 19	54.3	188
20 – 29	45.9	412
30 – 39	36.7	215
40 – 49	33.6	116
50 – 59	29.2	96
60 – 69	29.0	93
70 – 79	21.2	85
80 – 91	12.2	41
Unknown	-	11
Blood Alcohol Concentration		
Zero	26.3	655
0.001 – 0.049	30.2	43
0.050 – 0.079	48.6	35
0.080 – 0.149	60.9	115
0.150 +	58.9	314
Unknown	-	95

* Defined here as a fatal injury to an occupant of the car
** At least one car occupant fatality was caused by the car striking a hazard

Age, however, did show a very definite trend with cars driven by older drivers being less likely to have struck a roadside hazard that fatally injured an occupant. Conversely, because these were all cars in which an occupant was fatally injured in a crash, older drivers were more likely to be involved in other types of fatal crash.

The blood alcohol concentration (BAC) of the driver also showed a marked positive association with the likelihood of colliding with a fatal roadside hazard. In fact, cars driven by drivers above 0.08g/100mL were more than twice as likely to have struck a roadside hazard which fatally injured an occupant compared to zero BAC drivers. High BAC drivers presumably are more likely to lose control of their vehicle and leave the roadway.

4.5 Roadside Hazard Involvement per Fatality

This Section is based on all car occupants who died in a road crash in South Australia between 1985 and 1996. A "fatal hazard" car occupant is defined as a car occupant who was fatally injured because their car struck a roadside hazard. It should be noted that multiple fatalities in the same vehicle were classified differently in this regard in some cases.

Table 4.11 shows that nearly 39 per cent of car occupants fatally injured in crashes in South Australia died because their car collided with a roadside hazard.

Table 4.11
Car Occupant Fatalities in South Australia 1985-1996
and Roadside Hazard Involvement

	Fatal Hazard* %	**Total Car Occupant Fatalities (N)**
All Car Occupant Fatalities	38.8	1458

* The car occupant fatality was caused by the car striking a hazard

4.5.1 Characteristics of Fatally Injured Car Occupants

Male car occupants who died in crashes were more likely to have been killed by a roadside hazard than were female car occupants who died in crashes, as shown in Table 4.12.

The age of fatally injured car occupants shows a very definite trend with older fatalities being less likely to have died due to a collision with a roadside hazard. This finding is probably related to the similar association observed with the age of the driver in Section 4.4.4, assuming that cars generally contain occupants of similar ages.

The relationship between seated position in the vehicle of fatally injured occupants and roadside hazard involvement in their death is unexpected. Drivers and back seat passengers were more likely to have died as the result of a collision with a roadside hazard than were front seat passengers.

The seatbelt use of fatally injured car occupants was clearly associated with collisions with roadside hazards. Occupants who were wearing a seatbelt were much less likely to have died due to a collision with a roadside hazard than were occupants who were not wearing a seatbelt. This effect may be related to a greater susceptibility of non-seatbelt wearing occupants to fatal injuries when their vehicle strikes a roadside hazard and/or particular driving behaviours coincidentally associated with non-seatbelt use that make a collision with a fatal roadside hazard more likely.

Ejection from the vehicle of fatally injured car occupants appears to be unrelated to the role of fatal roadside hazards as does the survival time of the occupant.

Table 4.12
Characteristics of Fatally Injured Car Occupants
in South Australia 1985-1996 by Roadside Hazard Involvement

Characteristics of Fatally Injured Car Occupants	Fatal Hazard* %	Total Car Occupant Fatalities (N)
Sex		
Male	41.6	984
Female	33.1	474
Age		
00 – 09	20.5	39
10 – 19	51.0	263
20 – 29	48.2	450
30 – 39	35.0	214
40 – 49	33.6	125
50 – 59	32.7	104
60 – 69	25.4	114
70 – 79	20.2	99
80 – 94	14.0	50
Position in Vehicle		
Driver	40.7	892
Front seat passenger	32.3	365
Rear seat passenger	43.2	185
Unknown	-	16
Seatbelt Use		
Yes	29.8	533
No	45.1	501
Unknown	-	424
Ejection from Vehicle		
Yes	38.1	362
No	39.2	1070
Unknown	-	26
Survival Time		
Died same day	38.9	1274
Survived 1 day or more	38.0	184

* The car occupant fatality was caused by the car striking a hazard

4.6 Roadside Hazard Location

Table 4.13 shows the location of roadside hazards that caused the death of at least one car occupant in South Australia between 1985 and 1996. It can be seen that only 10 per cent of the fatal roadside hazards were located on private property adjacent to the roadway. The remaining 90 per cent were either on the road reservation or the median strip. This means that changes in the location, or the removal, of the majority of roadside hazards would not require the cooperation of private property owners.

Table 4.13
Location of Roadside Hazards Causing Car Occupant Fatalities in South Australia 1985-1996

Location of Fatal Roadside Hazard	Number	Percentage
Road reservation	409	83.5
Median strip	31	6.3
Private property	50	10.2
Total	**490**	**100.0**

Note: hazards fatally injuring multiple car occupants in the same crash are only counted once

The distance from the edge of the roadway of roadside hazards that caused the death of at least one car occupant is shown in Table 4.14. It can be seen that 11 per cent of fatal roadside hazards were less than 1 metre from the roadway, 55 per cent were less than 4 metres, and that 91 per cent were less than 9 metres from the roadway. The average distance of all the fatal roadside hazards from the roadway was 4.4 metres.

Table 4.14
Distance of Roadside Hazards Causing Car Occupant Fatalities from the Roadway in South Australia 1985-1996

Distance of Roadside Hazard from Road	Number	Percentage	Cumulative Percentage
0m	55	11.2	11.2
1m	64	13.1	24.3
2m	76	15.5	39.8
3m	73	14.9	54.7
4m	57	11.6	66.3
5m	49	10.0	76.3
6m	38	7.8	84.1
7m	21	4.3	88.4
8m	13	2.7	91.0
9m	11	2.2	93.3
10m	7	1.4	94.7
11m	1	0.2	94.9
13m	2	0.4	95.3
14m	5	1.0	96.3
15m	3	0.6	96.9
16m	2	0.4	97.3
17m	1	0.2	97.6
18m	2	0.4	98.0
20m	3	0.6	98.6
21m	1	0.2	98.8
22m	1	0.2	99.0
25m	1	0.2	99.2
28m	1	0.2	99.4
60m	1	0.2	99.6
80m	2	0.4	100.0
Total	**490**	**100.0**	

Note: distance is rounded to the nearest metre
Note: hazards fatally injuring multiple car occupants in the same crash are only counted once

However, Table 4.14 relates to fatal crashes in all speed limit zones. There is a marked difference in the distance of a fatal hazard from the edge of the road in urban areas compared with rural areas. Table 4.15 shows the distance of a fatal roadside hazard from the edge of the road in predominantly urban areas (speed limit less than 80 km/h). It can be seen that 22 per cent of fatal roadside hazards were less than 1 metre from the roadway and that 90 per cent were within 5 metres of the roadway. The average distance of all the fatal roadside hazards from the roadway in speed zones less than 80 km/h was 2.5 metres.

Table 4.15
Distance of Roadside Hazards Causing Car Occupant Fatalities from the Roadway in South Australia 1985-1996 in Speed Zones less than 80 km/hour

Distance of Roadside Hazard from Road	Number	Percentage	Cumulative Percentage
0m	34	22.2	22.2
1m	38	24.8	47.1
2m	30	19.6	66.7
3m	18	11.8	78.4
4m	12	7.8	86.3
5m	5	3.3	89.5
6m	3	2.0	91.5
7m	1	0.7	92.2
8m	3	2.0	94.1
9m	1	0.7	94.8
10m	3	2.0	96.7
14m	2	1.3	98.0
15m	2	1.3	99.3
16m	1	0.7	100.0
Total	**153**	**100.0**	

Note: distance is rounded to the nearest metre
Note: hazards fatally injuring multiple car occupants in the same crash are only counted once

By comparison, 6 per cent of fatal roadside hazards were less than 1 metre from the roadway and 90 per cent were within 8 metres of the roadway in speed zones of 80 km/h or higher. The average distance of all the fatal roadside hazards from the roadway in these speed zones was 5.3 metres.

It is notable that in high speed limit zones (80 km/h and above), 28 per cent of the fatal hazards were less than 3 metres from the edge of the road (Table 4.16) compared with 67 per cent of the fatal hazards in low speed limit zones (less than 80 km/h) (Table 4.15).

Table 4.16
Distance of Roadside Hazards Causing Car Occupant Fatalities from the Roadway in South Australia 1985-1996 in Speed Zones 80 km/hour or higher

Distance of Roadside Hazard from Road	Number	Percentage	Cumulative Percentage
0m	21	6.2	6.2
1m	26	7.7	13.9
2m	46	13.6	27.6
3m	55	16.3	43.9
4m	45	13.4	57.3
5m	44	13.1	70.3
6m	35	10.4	80.7
7m	20	5.9	86.6
8m	10	3.0	89.6
9m	10	3.0	92.6
10m	4	1.2	93.8
11m	1	0.3	94.1
13m	2	0.6	94.7
14m	3	0.9	95.5
15m	1	0.3	95.8
16m	1	0.3	96.1
17m	1	0.3	96.4
18m	2	0.6	97.0
20m	3	0.9	97.9
21m	1	0.3	98.2
22m	1	0.3	98.5
25m	1	0.3	98.8
28m	1	0.3	99.1
60m	1	0.3	99.4
80m	2	0.6	100.0
Total	**337**	**100.0**	

Note: distance is rounded to the nearest metre
Note: hazards fatally injuring multiple car occupants in the same crash are only counted once

4.7 Types of Roadside Hazards Causally Involved in Fatal Car Crashes

A fatal roadside hazard is defined here as a fixed object adjacent to the carriageway that caused the death of at least one occupant of a car as defined in Section 4.2.

Table 4.17 shows the types of fatal roadside hazards encountered by cars in this study. It can be seen that trees comprise the vast majority of these hazards. Stobie poles (concrete poles braced with steel sides) play a much less but still very significant role as do embankments (including cuttings). The remaining roadside hazards play a much smaller role in causing car occupant fatalities.

Table 4.17
Type of Roadside Hazards Causing Car Occupant Fatalities in South Australia 1985-1996

Type of Fatal Roadside Hazard	Number	Percentage
Tree	287	58.6
Stobie pole	94	19.2
Embankment	52	10.6
Guard rail	11	2.2
Drain	9	1.8
Fence	9	1.8
Wall	6	1.2
Building	5	1.0
Light pole	4	0.8
Bridge	4	0.8
Miscellaneous	9	1.8
Total	**490**	**100.0**

Note: hazards fatally injuring multiple car occupants in the same crash are only counted once

Table 4.18 shows the number and percentage of fatalities caused by specific roadside hazards and the percentage of all car occupant deaths attributable to specific roadside hazards. Twenty three per cent of all fatally injured car occupants died because of a collision with a tree, and eight per cent with a Stobie pole.

Table 4.18
Car Occupants Fatally Injured by Roadside Hazards in South Australia 1985-1996

Fatal Roadside Hazard	Number of Fatalities	Percentage of Hazard Fatalities	Percentage of All Fatalities
Tree	330	58.3	22.6
Stobie pole	113	20.0	7.8
Embankment	56	9.9	3.8
Guard rail	13	2.3	0.9
Drain	9	1.6	0.6
Fence	9	1.6	0.6
Wall	6	1.1	0.4
Building	8	1.4	0.5
Light pole	6	1.1	0.4
Bridge	4	0.7	0.3
Miscellaneous	12	2.1	0.8
Total	**566**	**100.0**	**38.8**
Not Killed by Roadside Hazard	**892**	**-**	**61.2**
Total	**1458**	**-**	**100.0**

Note: hazards fatally injuring multiple car occupants in the same crash are counted once for each such fatality

Further information on the individual types of fatal roadside hazards is given in the following Sections that examine each type of hazard in detail.

4.7.1 Trees

Trees were by far the most serious fatal roadside hazard on South Australian roads (see Figure 4.1 for an example). Between the years 1985 and 1996, 287 cars crashed into one or more trees resulting in the deaths of 330 occupants (252 single fatalities, 28 double fatalities, 6 triple fatalities and 1 quadruple fatality).

Figure 4.1
Car ran wide on a left hand bend on a 2-lane 100 km/h road
(85 km/h advisory speed sign). Driver fatally injured in collision with tree

The trees were classified into the following groups: 243 were large trees; 31 were small trees; and 13 were clumps of trees. A small tree was defined as a tree that would be expected to break at the trunk when struck by a car.

Out of the 287 collisions with trees, 54 (18.8%) of the crashes also involved the car rolling over. In the remaining 233 (81.2%) cases the car occupant(s) died directly from the impact with the tree.

Almost all of the crashes in which a collision with a tree caused the death of a car occupant involved only one car (282 cases or 98.3% of the total). The remaining five crashes in which a tree was struck involved two vehicles.

In some of these crashes the tree had been planted alongside the road by Transport SA (then the Highways Department of South Australia). These cases included 6 fatal crashes in a two kilometre section of highway in which cars struck trees that had been planted on the median strip.

4.7.2 Stobie Poles

Most utility poles in South Australia consist of two rolled steel joists separated by concrete. They are commonly referred to as Stobie poles, after the name of the engineer in the Adelaide Electric Supply Company who developed this design.

While collisions with Stobie poles did not account for nearly as many deaths as did collisions with trees, they were still a very serious problem. Between the years 1985 and 1996, 94 cars hit Stobie poles resulting in the deaths of 113 occupants (76 single fatalities, 17 double fatalities and 1 triple fatality).

Out of the 94 collisions with Stobie poles, 14 (14.9%) of the crashes also involved the car rolling over. In the remaining 80 cases (85.1%) the car occupant(s) died directly from the impact with the Stobie pole.

Most of the crashes in which a collision with a Stobie pole caused the death of a car occupant were single car crashes (82 crashes or 87.2%). Only 12 (12.8%) of these crashes involved two vehicles.

Figure 4.2 illustrates a collision with a Stobie pole in a rural area. The car was travelling along a 100 km/h road. Approaching a right hand bend, the driver moved to the left partly onto a gravel shoulder to allow a vehicle behind to pass. On attempting to return to the sealed road surface the driver lost control and the car yawed clockwise across to the other side of the road where it struck a Stobie pole. A fire then started in the occupant compartment. The driver, who was seriously injured, was extricated by passing motorists but the front passenger, who was also severely injured, was unable to be removed and was incinerated.

Figure 4.2
A collision with a Stobie pole in a rural area

4.7.3 Light Poles

Although they are all utility poles, these light poles are listed separately from Stobie poles in this report because they were of cast iron tubular construction of a type installed to carry overhead wires for a tramway system.

Six occupants died in four cars that struck a light pole. These crashes typically resulted in very severe deformation of the car, with three of the six fatally injured occupants being ejected. In one case the car caught fire and the driver was incinerated.

4.7.4 Embankments and Cuttings

There were 52 crashes involving embankments or cuttings leading to the deaths of 56 car occupants (49 single fatalities, two double fatalities and one triple fatality). Embankments were defined as a steep downward slope, and a cutting as a steep upward slope, at the side of the road. These two particular types of crash are considered separately below.

The 34 crashes in cuttings resulted in the deaths of 36 car occupants. The fatality types fell into 3 main categories: 4 deaths in 4 collisions resulted directly from the force of the impact of the car with the face of the cutting; 31 deaths in 30 collisions with the face of the cutting which caused the car to roll over; including 19 deaths in 18 rollovers in which the fatally injured occupants were ejected from the car.

The 18 embankment crashes resulted in the deaths of 20 car occupants. The fatality types also fell into 3 main categories: 8 deaths in 6 collisions resulted directly from the force of the impact at the bottom of the embankment; 12 deaths in 12 crashes resulted from the car rolling over down the embankment; including 8 deaths in 8 rollovers in which the fatally injured occupants were ejected from the car.

4.7.5 Guard Rails

In South Australia from 1985 to 1996, 11 collisions of a car with a guard rail resulted in the deaths of 13 occupants.

In 6 of the crashes, resulting in 7 fatalities, the impact with the guard rail caused the car to roll over. In two of these collisions the car struck the end of the guard rail.

In two other crashes, resulting in two fatalities, the occupants were killed by the intrusion of the end of a guard rail into the car. A single occupant in one crash was also killed by the force of their car’s collision with the side of a guard rail.

In one crash, two occupants were killed in a head on collision with another vehicle after their car was deflected back onto the road by a guard rail. In the remaining crash, a single car occupant was killed when the car was deflected back across the road after a collision with a guard rail and then struck a concrete post.

4.7.6 Fences

Nine cars ran off the road and crashed into a fence, resulting in the death of one occupant in each case.

Four of the crashes involved chain wire fences with metal posts and rails. In three cases an occupant was impaled on a metal rail which penetrated the car and one other occupant was ejected and then impaled on a metal rail.

Two of the crashes involved chain wire fences with concrete posts. In one case the impact of the car with the post caused the fatal injuries to the occupant and in the other case, an intoxicated driver was attempting to leave the moving car and hit his head on the concrete post.

The remaining crashes involved: a driver hitting a brush fence and receiving apparently minor but ultimately fatal injuries; a driver being impaled by a wooden fence rail penetrating the car; and a driver being impaled by a permapine fence rail coming through the windscreen.

4.7.7 Drains

Nine cars ran into a drain and/or an associated structure, leading to the death of one occupant in each case. In three crashes the car impacted the far side of a deep drainage channel killing an occupant (one drain was formed from concrete and two from earth works).

In three cases a shallow drainage ditch at the side of the road caused the car to roll over, resulting in the death of an occupant. In one further case an impact with the edge of a small concrete drain also caused the car to roll over. An occupant was ejected and sustained fatal injuries.

In another crash, a car struck the stone end of a drain running underneath the road. An occupant of the car was fatally injured.

In the remaining crash, a car rolled into a deep drain running under the road. The driver of the car was knocked unconscious and drowned.

4.7.8 Walls and Buildings

Six cars crashed into a wall, resulting in the death of one occupant in each case. Three of the walls were of brick construction and three were stone. The cause of the fatal injuries in each case was the collision with the wall.

In the five cases in which a car ran off the road and struck a building, eight occupants were fatally injured.

In one of these crashes, the car rolled before hitting the building roof killing the four occupants. In another case, the driver was crushed between a semitrailer and the building.

4.7.9 Bridges

Three of these four crashes occurred on the same bridge. In two cases a car ran onto a narrow median and then swerved back to the left, crashing through a chain wire fence and falling from the bridge. In the other case on this bridge the car crossed the median and crashed into a pole. The driver was ejected and fatally injured.

In the remaining case, a driver died when the car struck a concrete column supporting an overpass.

4.7.10 Miscellaneous Roadside Hazards

There were nine different miscellaneous roadside hazards identified as causing the death of twelve car occupants in this study:

- a bus shelter,
- a raised concrete cover of a storm water drain (located in the median of a State highway),
- a concrete milk loading platform,
- a lateral shift marker sign,
- an old wagon fixed as advertising on private property,
- a railway signal pole,
- a rock at the side of the road,
- a traffic signal pole,
- a timber utility pole.

4.8 Location of Specific Roadside Hazards

Table 4.19 shows the distribution of crashes involving the most common types of fatal roadside hazards according to geographical region, speed limit and type of roadway.

It can be seen in each of the classifications in Table 4.19 that trees accounted for most of the fatal roadside hazards.

Stobie poles are the most common fatal roadside hazard in the Adelaide metropolitan area and, consequently, play a major role in fatal crashes in 60 km/h zones.

Embankments and cuttings played a role in fatal crashes mostly in rural areas, as would be expected, and particularly in regions where there are few naturally occurring trees at the roadside.

Table 4.19
Location of Roadside Hazards Causing Car Occupant Fatalities in South Australia 1985-1996 by Specific Type of Hazard (Row Percentages)

Location of Fatal Roadside Hazards	Tree	Stobie Pole	Embankment	Other	Total Fatal Hazards (N)
Transport SA Region					
Adelaide metropolitan	52.6	28.9	4.8	13.6	228
Eastern	65.7	10.1	14.8	9.5	169
Mid north	66.7	14.0	8.8	10.5	57
Northern & Western	50.0	8.3	30.6	11.1	36
Location					
South East	64.3	11.3	14.8	9.6	115
Adelaide Surrounds	66.3	15.8	8.4	9.5	95
Adelaide Plains North	60.0	22.5	3.8	13.8	80
Adelaide Plains	26.2	54.1	0.0	19.7	61
Victor Harbor	77.1	8.6	8.6	5.7	35
York Peninsula	73.9	8.7	13.0	4.3	23
Eyre Peninsula	57.1	4.8	28.6	9.5	21
North	40.0	20.0	25.0	15.0	20
Clare Valley	64.7	17.6	5.9	11.8	17
North East	41.7	8.3	41.7	8.3	12
Sturt Highway	28.6	14.3	14.3	42.9	7
Kangaroo Island	100.0	0.0	0.0	0.0	4
Speed Limit Zone					
60 km/h	41.1	39.1	2.0	17.9	151
80 km/h	62.8	20.9	4.7	11.6	43
100 km/h	67.3	14.5	12.7	5.5	55
110 km/h	67.4	7.1	16.7	8.8	239
Other	-	-	-	-	2
Type of Roadway					
Highway	68.3	12.7	10.6	8.5	189
Local Adelaide metropolitan	65.5	13.8	5.2	15.5	58
Local rural	58.4	13.9	17.5	10.2	166
Main Adelaide metropolitan	29.9	50.6	0.0	19.5	77

4.9 Summary

This review of the role of roadside hazards in crashes in which a car occupant was fatally injured in South Australia from 1985 to 1996 has shown that:

- a collision with a roadside hazard fatally injured at least one car occupant in 40 per cent of these crashes,
- a collision with a roadside hazard fatally injured at least one car occupant in 39 per cent of all cars in which an occupant died,
- a collision with a roadside hazard was the immediate cause of death of 39 per cent of all fatally injured car occupants.

The crash involvement rate of fatal roadside hazards in crashes in which a car occupant was fatally injured was found to be greatest:

- on the weekend,
- late at night and especially after midnight,
- in the Adelaide metropolitan and south eastern part of South Australia,
- on local streets and minor rural roads (due to higher density of roadside objects very close to the edge of these roads),
- in lower speed limit zones (due to higher density of roadside objects very close to the edge of the road in lower speed limit zones),
- on wet roads,
- on mid-block and curved sections of road,
- in single vehicle crashes.

The involvement rate per car of fatal roadside hazards in crashes in which a car occupant was fatally injured was found to be greatest:

- in non-commercial cars,
- in older cars,
- in cars that ran partly onto the loose shoulder of a sealed road,
- in cars that didn't roll over,
- in cars containing only one or more than two occupants,
- in cars with younger drivers,
- in cars with alcohol intoxicated drivers.

The involvement rate per fatally injured car occupant of fatal roadside hazards in crashes in which a car occupant was fatally injured was found to be greatest for:

- males,
- younger occupants (excluding the 0-9 age group),
- drivers and rear seat occupants,
- occupants not wearing a seatbelt,

Ninety per cent of the roadside hazards that fatally injured car occupants were located on the road reservation, including the median strip, and 76 per cent were within 5 metres of the road edge.

The most common types of roadside hazard which fatally injured a car occupant were:

- trees (58% of roadside hazard deaths and 23% of all car occupant deaths),
- Stobie poles (20% of roadside hazard deaths and 8% of all car occupant deaths),
- embankments and cuttings (10% of roadside hazard deaths and 4% of all car occupant deaths),
- guard rails (2% of roadside hazard deaths and 1% of all car occupant deaths).

Other less frequently occurring groups of roadside hazard included drains, fences, walls and buildings, light poles and bridges. The contribution of these groups to the overall fatal roadside hazard problem was not great, but in many cases there is a clear need for remedial action.

Trees were found to be the major fatal roadside hazard in most regions of South Australia. Stobie poles were primarily a cause of fatal injuries in low speed limit urban areas while embankments and cuttings were associated with fatal car crashes mainly in rural areas.

5. DISCUSSION

Our main aim in this report has been to document the nature and the extent of the involvement of roadside hazards in car crashes in South Australia, with emphasis on fatal cases.

Part of this report is based on the Traffic Accident Reporting System data base. As the main source of information on road crashes of all severities in South Australia, it is in urgent need of updating, both in terms of the available information, which comes from the police accident report form, and the coding format and file structure of the data base itself. Far better systems are in use in other countries, particularly in certain States of the USA. Fortunately, the Coroner approved our access to reports compiled for his Office on fatal crashes. These reports are usually very detailed and formed a sound basis for this examination of the role of roadside hazards in crashes which resulted in the deaths of one or more car occupants.

We have used the literature review to place our findings in a wider context, specifically by comparing our overall findings with the results of similar research conducted in the United States and other countries. The literature review provides descriptions of countermeasures which have been developed for some of the more common roadside hazards but detailed recommendations for the further application of these and other countermeasures to specific locations in South Australia are, with some exceptions, beyond the scope of this report.

5.1 Extent of the Roadside Hazard Problem in South Australia

In South Australia, on average, each week one car occupant dies as a result of their car crashing into a roadside hazard and each day one car occupant is seriously injured. The consequent human suffering and economic losses are considerable for both the people involved and for the State in general.

The extent of the problems associated with roadside hazards in South Australia is not unique. From 1985 to 1996, 40 per cent of the crashes resulting in fatal injuries to car occupants involved a roadside hazard that caused the death of an occupant. In the United States in the late 1970s it was estimated that 40 per cent of all road accident fatalities, and 50 per cent of the fatal road crashes not involving pedestrians, occurred on the roadside, off the paved roadway (Tignor et al, 1982). In Sweden, it has been estimated that roadside hazard crashes account for 25 per cent of all road accident fatalities (Nilsson and Wenall, 1998).

5.2 What Can be Done about Roadside Hazard Crashes?

5.2.1 Change Driver Behaviour

The rate at which roadside hazards were involved in crashes was greatest at night, especially after midnight. These are times of reduced visibility, with driver fatigue and increased alcohol use all contributing to a greater likelihood that a driver will lose control of the car, which will then run off the road with the risk of crashing into a fixed object or rolling over down an embankment.

We found that drivers who had a high blood alcohol level (often very high) were twice as likely to be involved in a fatal roadside hazard crash than were sober drivers. Measures aimed at reducing impaired driving, particularly impairment due to alcohol, are likely to be particularly effective in reducing the frequency of crashes involving roadside hazards. (Similarly, a reduction in the incidence of roadside hazards is likely to be one of the most effective countermeasures for the harm resulting from driving when impaired by alcohol.)

A distinct driver age effect was also found whereby the likelihood of a car occupant being fatally injured because of a collision with a roadside hazard decreased as the age of the driver increased. This indicates that the young are particularly at risk of colliding with roadside hazards.

The marked difference in fatal roadside hazard crash involvement by seatbelt use may provide an indirect indication of driver risk taking behaviour. The rate of fatal roadside hazard crash involvement was found to be much greater among those fatally injured car occupants who had not been wearing a seatbelt. This may also reflect the greater likelihood of a car occupant who was not wearing a seat belt sustaining a fatal injury in a crash of a given severity, for example by being ejected from the car during the crash.

The influence of travelling speed, not simply “speeding” is discussed briefly in the next section.

5.2.2 Implications for Road and Traffic Engineering

Roadside hazards were found to play a greater role in crashes on mid-block sections of road, particularly on curves, rather than at intersections. Particular attention therefore needs to be paid to the elimination or control of roadside hazards alongside curves, on both sides of the road.

A car which enters a curve at too high a speed is likely to run off the road on the outside of the curve. However, off road excursions often also occur on the inside of the curve when a car runs partly onto the outside earth or gravel shoulder on a left hand bend and then, when the driver attempts to regain the paved road, yaws out of control back across the roadway. The incidence of loss of control in such situations can be significantly reduced by sealing part of the shoulder of the road and line marking the outer boundary of the traffic lane (eg: Armour et al, 1989; Corben et al, 1997). Appropriate design of the horizontal alignment of new roads, and in the reconstruction of existing roads, also has great potential to reduce the incidence of crashes involving roadside hazards adjacent to curves (Corben et al, 1997).

The distance of the fatal hazards from the edge of the road in 80 km/h or higher speed limit zones was less than 9 metres in 90 per cent of the cases (Table 4.16). This supports the recommendation that, at least in rural areas, the roadsides should preferably be clear of fixed objects and other hazards for a distance of 9 metres (Ogden, 1996). However, that does not mean that existing clear zones which extend further from the roadway should be degraded by, for example, the planting of substantial trees, as shown in Figures 5.1 to 5.3 later in this chapter. Where removal of a roadside hazard is not possible the installation of a guard rail or realignment of the road, as noted above, may be effective countermeasures.

The distance of the fatal hazards from the edge of the road in speed limit zones of less than 80 km/h was less than 6 metres in 90 per cent of the cases (Table 4.15). However, two thirds of the fatal hazards in these speed limit zones were less than 3 metres from the edge of the road. There would therefore be considerable benefit from a clear zone of even 1 or 2 metres at the edge of the road in low speed zone areas.

Any reduction in travelling speeds, whether a consequence of changes in enforcement practices or a reduction in speed limits, would be expected to result in fewer drivers losing control of their vehicles. This in turn would reduce the number of vehicles running off the road and exposing the occupants to the risk of injury from a collision with a roadside object. It would also mean that when such collisions did occur they would be at lower, and hence less injurious, impact speeds.

The large number of Stobie (utility) poles adjacent to roads and streets in South Australian urban areas results in this type of roadside hazard playing a proportionally greater role in fatal crashes in 60 km/h speed limit zones rather than in higher speed zones (Table 4.19). This does not mean that travelling speed is not a risk factor for involvement in a collision with a Stobie pole. It is rather a reflection of their relative frequency at the roadside in urban and rural areas in the State.

Given the proportionally greater role of roadside hazards in fatal car crashes at night, it is important to ensure that there is adequate delineation of the edge of the paved road to minimise the risk of a driver unintentionally allowing his or her car to run off the sealed surface. Johnston (1981) found that while the presence, and width, of a line marking the edge of the traffic lane assisted all drivers to stay in the lane on a curve at night it was particularly helpful for drivers at even comparatively low (0.04) blood alcohol levels. It is therefore unfortunate that existing traffic engineering practice, even on sections of national highway in South Australia, is to provide edge marking only if the roadway is wide enough for a traffic lane of at least the standard width. In other words, if the roadway is unusually narrow, the motorist is denied the benefit of an edge line when it is most needed.

5.3 Comments on Specific Types of Roadside Hazards

In this Section we present some brief comments on the main types of fatal roadside hazards which were identified in this study.

5.3.1 Trees

Naturally-occurring trees along the roadside contribute in many ways to the richness of our environment. However, almost one quarter of the car occupant deaths in crashes in South Australia from 1986 to 1995 resulted from a collision with a tree.

In some circumstances it may be considered appropriate to remove a tree which clearly presents an unacceptable hazard to motorists. In other cases it may be possible to erect a longitudinal barrier, as shown in Figure A5 in Appendix A, to reduce the risk of a vehicle striking the tree. In all cases, however, any measure which will reduce the risk of a vehicle running off the roadway will obviously reduce the risk of a collision with a tree, or any other roadside hazard.

Unfortunately it is accepted practice in South Australia to plant trees in those parts of the road reservation that should be dedicated clear zones. One consequence of this practice is illustrated in Appendix A, which describes the fatal collisions with trees which have been planted on the median on a two kilometre length of State highway. These trees accounted for an average of about one car occupant fatality every two years from 1985 to 1995. A wire rope barrier has now been installed between the road and the trees in the vicinity of the location of one of these fatal crashes (Figure A5) but all of the other trees on the median remain exposed to passing traffic elsewhere in this two kilometre stretch of highway.

Figure 5.1
Damage to the car which struck the tree shown in Figure 5.2

Even where a road has been designed with a wide median, trees planted more than 9 metres from the edge of the carriageway can still be a fatal hazard. Figure 5.1 shows the damage to a car in which two occupants died when it ran off the road and struck a tree which was located just over 10 metres from the edge of the carriageway (Figure 5.2). The departure angle of the car is shown in Figure 5.3.

Figure 5.2
Tree struck by the car shown in Figure 5.1

Figure 5.3
Departure angle from the roadway prior to the collision with the tree shown in Figure 5.2.

5.3.2 Stobie Poles

Stobie poles (utility poles comprising two rolled steel joists separated by concrete) were as hazardous as trees at the roadside in terms of the risk of a car occupant being injured in a collision. However, because there are fewer Stobie poles than trees, they were the second most commonly struck roadside hazard. Even so, collisions with Stobie poles accounted for 8 per cent of car occupant deaths and were involved in 9 per cent of serious injury crashes.

It has sometimes been claimed that collisions with Stobie poles protect pedestrians, who would otherwise be at risk of being struck by the out of control car. That possibility was investigated in the course of the Adelaide in-depth accident study conducted by the Road

Accident Research Unit in 1976-77. No cases were found in which a pedestrian was in the immediate vicinity of a collision between a car and a Stobie pole (McLean et al, 1981).

This same study (McLean et al, 1981) also found that the majority of collisions with Stobie poles that were observed may well have been averted had the Stobie poles been set back from the road to the property boundaries.

In South Australia there is a formal committee charged with dealing with environmental matters associated with overhead power lines, specifically the need for tree pruning to keep the foliage away from the wires. In New South Wales there is a similar committee charged with dealing with the effects on road safety of the poles supporting the overhead power lines. Damage to street trees appears to be a greater object of community concern in South Australia than the average of 8 deaths and 70 hospital admissions each year from collisions with Stobie poles.

Perhaps the apparent lack of concern in the community about Stobie poles, and other utility poles, exists because the severity of the hazard they present is not well understood. A collision with a Stobie pole at 60 km/h is comparable in severity to driving off a 14 metre high cliff, or the roof of a three story building. If our streets and roads were bordered by a 14 metre sheer drop, rather than a footpath, no one would drive in the kerb lane.

It is sometimes said that power lines in urban areas should be put underground. In some places that is happening. However the costs involved are considerable. The City of Kensington and Norwood, before the recent local government amalgamations, had a program to underground all overhead power lines in the Council area. The annual funds that were available meant that it would have taken 100 years to complete the program.

The hazards associated with reliance on overhead power transmission lines, and hence the need for utility poles adjacent to roadways, contrast markedly with the high level of safety demanded, quite appropriately, in the provision and use of electricity in industrial and domestic applications. As a result, the savings derived from the economical transmission of electricity by means of overhead cables need to be balanced against the cost to the community of the deaths, injuries and property damage resulting from vehicle collisions with the utility poles which support the overhead wires. Part of that cost is borne by the Compulsory Third Party Scheme.

5.3.3 Light Poles

As noted previously, the light poles involved in the fatal crashes in this study were of rigid construction, installed originally to carry overhead conductors for a tramway system.

In the twelve years of fatal car crashes on which this report is based there were no cases in which a car occupant was killed in a collision with a slip-base or frangible pole such as the type illustrated in Figure 5.4. The driver of the car shown in Figure 5.5 lost control when a tyre blew out on an 80 km/h divided road. Despite the collision with the pole the driver was not injured.

Figure 5.4
Slip-base pole struck by the car shown in Figure 5.5

Figure 5.5
Car which struck the pole shown in Figure 5.4

5.3.4 Embankments and Cuttings

While the hazards presented to car occupants by embankments and cuttings were found to be much less common than those associated with trees and Stobie poles, crashes in which a car rolled down a steep embankment or crashed into the face of a cutting accounted for nearly 4 per cent of car occupant fatalities in South Australia from 1985 to 1996.

Embankments adjacent to new roads should have slopes of no more than 1 in 5 or 1 in 6 (Pak-Poy & Kneebone, 1988; Ogden, 1996). Where this is not possible, and on current roads with steep faced embankments or cuttings, consideration needs to be given to the installation of guard rails to protect vehicle occupants from severe collisions and vehicle rollovers.

5.3.5 Guard Rails

The purpose of a guard rail is to protect the occupants of a vehicle which runs off the road. It is designed to stop the vehicle from going further from the road and to slow it down as it slides along the rail. The impact with the guard rail should not be so severe as to injure the occupants of the car or redirect the car back across the roadway where it may crash into another vehicle.

It is not realistic to expect all guard rails to perform exactly as intended in all cases but 13 car occupants died in 11 collisions with a guard rail in the crashes reviewed in this study.

The main aim of this study, as noted above, is to document the nature and extent of the problem presented by roadside hazards. However, fatal crashes with guard rails are clearly worthy of more detailed investigation in the near future, preferably supplemented by the investigation of cases in which guard rails have performed as intended. There would also be merit in a review of recent developments in the design of guard rails, including a French design which is constructed from softwood logs and is widely used on minor rural roads in that country.

5.3.6 Fences

A collision with a fence would appear to be unlikely to fatally injure the occupant of the striking car. However 9 occupants died in 9 crashes when the car ran into a fence on the boundary of a private property. The fatal injuries were inflicted by the top rail of the fence, which skewered the occupant in 6 of the 9 cases. Four of these rails were of tubular steel and two were made of timber.

There are still many chain wire fences which have a tubular steel top rail adjacent to signalised pedestrian crossings in Adelaide. There has been at least one car occupant fatally injured in a collision with one of these fences, before the period covered by this study. There would appear to be a strong case to replace all of the remaining fences of this type with fences which do not have a substantial top rail.

5.3.7 Bridges

As noted earlier in this report, three of the four cases involving bridges occurred on the one bridge. This bridge has entirely inadequate fencing which has accounted for at least one further fatality since the end of the period covered by this report.

6. CONCLUSIONS

Drivers sometimes leave the roadway unintentionally for various reasons. For example, they may have fallen asleep, been intoxicated, or have lost control as a result of an unexpected incident in the car or on the roadway itself. Whatever the reason for the off-road excursion, the penalty imposed on the occupants of the car is often death or serious injury.

Roadside hazards were the immediate cause of at least one death in 40 per cent of all crashes in which a car occupant was fatally injured in South Australia from 1985 to 1996.

Collisions with roadside hazards were the immediate cause of 39 per cent of all car occupant deaths during those years.

Roadside hazards also played a role in 38 per cent of all car crashes in which an occupant was admitted to hospital in South Australia from 1994 to 1996.

Countermeasures aimed at reducing travelling speed, drink driving, and driver fatigue are likely to decrease the frequency of roadside hazard crashes, probably to a greater degree than crashes in general. Measures which increase seat belt use, particularly in rural areas, will assist in reducing the severity of those injuries that do occur in all crashes, including those involving roadside hazards. However, reliance on attempts to change driver behaviour alone will not be an adequate response to the dangers presented by roadside hazards.

There is much that can be done to further improve the safety of our roads and roadsides. This is important because the design, construction and maintenance of the roads and roadsides in South Australia are almost entirely within our control, subject to the availability of funds. The regulation of road traffic, particularly by means of speed limits, is also largely within our control. By comparison, we have limited control over the design of vehicles and, as implied above, attempts to change driver behaviour are fraught with difficulties.

Cars that ran onto the unsealed shoulder of the road were 20 per cent more likely to be involved in a fatal collision with a roadside hazard than were cars involved in other types of crash in which an occupant was fatally injured. Sealing part of the shoulder of the road and providing edge lining reduces the risk of a driver running off the road, particularly on curves. The condition of the road surface, and the provision of adequate drainage, can be critical factors in inclement weather in ensuring that a driver is able to retain control of his or her car (see Appendix A).

The potential benefits of clear zones alongside roads are evident in this study. More than half of the fatal hazards in the crashes in this study were within 3 metres of the edge of the road, partly reflecting the number of crashes involving poles in urban areas. Overall, 90 per cent of the roadside hazards which were struck by a car, fatally injuring at least one occupant, were located less than the recommended 9 metres from the edge of the roadway.

Trees were by far the most common roadside hazard in South Australia, accounting for 23 per cent of all deaths to car occupants and being involved in 17 per cent of all serious injury crashes. Some of the fatal crashes were with trees which had been planted by the then Highways Department in what are should be clear zones (See Appendix A).

Collisions with Stobie poles accounted for 8 per cent of car occupant deaths and 9 per cent of serious injury crashes, which represent an average of about 10 deaths and 70 hospital admissions per year in South Australia. As a community we pay a high financial and human price for this economical method of power transmission via overhead wires.

There were no fatalities recorded in any collisions with slip-base light poles in the accident data which was reviewed in this study. This design of pole saves lives.

Fifty six car occupants were fatally injured when their car either rolled down a steep embankment or struck the face of a cutting. Nine other occupants died when the car in which they were travelling ran off the road into a drainage channel. many of these deaths could have been prevented by either changes to the earthworks alongside the road or the provision of guard rails.

Eleven collisions between a car and a guard rail accounted for 13 deaths, 9 of which occurred when a car either rolled on hitting the guard rail or was impaled on the end of the rail. As with slip-base poles, the cases in which a guard rail performed as intended did not appear in the fatal accident data files. However, these 11 fatal cases show that further investigation and refinement of the design and installation of guard rails is warranted.

Nine car occupants died in 9 collisions with fences on the boundaries of private property. Six of the 9 fatally injured occupants were impaled by the top rail of the fence. Many similar fences which were erected by Transport SA (then the Highways Department) adjacent to signalised pedestrian crossings in the Adelaide area have yet to be replaced, even though at least one has been a direct cause of fatal injury to a car occupant.

This study has shown that the investigation and monitoring of the causes and consequences of road crashes in South Australia is hampered by the inadequacies of the main source of data, the Traffic Accident Reporting System.

7. RECOMMENDATIONS

7.1 Regulation of Road User Behaviour

Measures which reduce the risk of a driver losing control and running off the road will obviously reduce the frequency of crashes involving roadside hazards. It is therefore recommended that:

Current levels of enforcement of legislation relating to speed and drink driving be maintained or increased.

If the driving task is made easier by reducing travelling speeds, drivers will make fewer mistakes and be better able to correct those mistakes that are made before losing control and running off the road. In so far as adequately enforced speed limits will reduce travelling speeds, it is recommended that:

110 km/h zones in rural areas of South Australia be eliminated and that the speed limit on all roads in urban areas be reduced to 50 km/h.

7.2 Road Design, Construction and Maintenance

The horizontal alignment of the road, the condition of the road surface, and the provision of sealed shoulders and edge lines and are all important factors in assisting a driver to avoid running off the road. It is therefore recommended that:

The horizontal alignment of the road, the condition of the road surface, and the provision of sealed shoulders and edge lines be subject to timely review, initially on all State and National Highways in South Australia, and a case be made for the provision of funds to permit early rectification of such deficiencies as may be identified.

Sealing part of the shoulder of the road and providing edge lining in particular reduces the risk of a driver running off the road, particularly on curves. As noted in Section 5.2.2, existing traffic engineering practice does not permit the provision of edge lining on substandard sections of narrow roadway, when the delineation provided by the lines is most needed. As some sections of even National Highway in South Australia are affected in this way it is recommended that to make the driving task easier:

As soon as practicable, shoulders be sealed to a width of at least half a metre on all highways and major roads in South Australia, commencing with curved sections of road, and despite standard traffic engineering practice, edge lining be provided on highways and major roads in South Australia regardless of the width of the road.

7.3 Trees

Trees planted along roadsides can and do increase the risk of death or injury to road users whose vehicle has run off the road, for whatever reason. It is therefore recommended that:

The roadside tree planting policies of Transport SA and local government authorities be reviewed taking into account current best road safety practice to prevent new planting in hazardous locations and to rectify the dangers posed by trees which have been planted within 9 metres of rural roads. In urban areas a clear zone should be maintained within a minimum of 1 metre from the edge of the road and preferably 3 metres or more wherever practicable.

7.4 Stobie Poles

The degree of morbidity and mortality from collisions with Stobie poles in South Australia, particularly in urban areas, would be unacceptable if it were due to an infectious disease, or food contamination. The difficulties confronting resolution of the danger to road users associated with these poles are very considerable. Nevertheless, it is recommended that:

A standing committee similar to the NSW Hazardous Pole Program Committee be convened to identify and implement all practicable ways of reducing the deaths and injuries resulting from collisions with Stobie poles.

7.5 Guard Rails

While recognising that cases in which a guard rail performed as intended when struck by a car did not appear in the crashes reviewed for this study, nevertheless some collisions with guard rails did result in death and injury. It is therefore recommended that:

Casualty crashes with guard rails be the subject of detailed investigation, supplemented by the investigation of cases that can be identified in which a guard rail has performed as intended.

As the design and construction of guard rails continues to evolve, it is recommended that:

A review be conducted of recent developments in the design of guard rails, including a French design which is constructed from softwood logs and is widely used on minor rural roads in that country.

7.6 The Traffic Accident Reporting System

There are many improvements which could be made to the current system of reporting on and recording information from road accidents in South Australia. As the ready availability of accurate and timely information is central to the investigation and monitoring of the causes and consequences of road accidents and the effectiveness of countermeasures it is recommended that:

The system of reporting on road accidents in South Australia be changed with reference to the systems operating elsewhere, including the United States.

Other matters which may be deserving of attention in relation to reducing the deaths and injuries associated with roadside hazard crashes are mentioned in Chapters 5 and 6.

ACKNOWLEDGMENTS

This research project was made possible by a grant from the Motor Accident Commission.

The research program of the NHMRC Road Accident Research Unit at the University of Adelaide is also supported by a Research Unit grant from the National Health and Medical Research Council.

Transport SA provided an engineer, Michael Anchor, on secondment to work on crash investigation and other tasks associated with this project. His assistance is gratefully acknowledged. Transport SA also provided a copy of the Traffic Accident Reporting System data base with the approval of the South Australia Police.

The Coroner gave permission for staff of the Unit to make copies of relevant Coronial records on fatal road crashes. Jana Skilins assisted with this work.

The opinions expressed in this report are those of the authors and are not necessarily shared by the above organisations.

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APPENDIX A

Roadside Planting

As noted in Section 5.3.1, on one particular two kilometre length of State highway there was an average of one fatal crash every two years into trees that had been planted on the median, or left unprotected on the median when the carriageway was duplicated. Seven people were fatally injured in these six crashes. There was also a fatal crash into a tree that appeared to have been planted to the left of the road in this two kilometre section.

Figure A1 shows a tree that was hit by a car that was, according to a following motorist, travelling at 90 km/h in a 110 km/h speed zone in heavy rain. Probably because three of the tyres on the car were bald, the car slowly began to yaw in a clockwise direction. It continued rotating until it ran onto the median and struck the tree shown, fatally injuring the driver.

Figure A1
Tree struck by car which hydroplaned off the road in heavy rain

Figure A2 shows the view of approaching traffic from a tree that was struck by a car driven by a driver who was intoxicated. The driver's view of the tree, which is indistinguishable in the illustration from the other trees on the median, is shown in Figure A3. Note that lateral shift marker boards are now present to warn drivers of the presence of a bend in the road. However, once a car leaves the road the boards and their supports become additional objects to hit.

Figure A2
View of approaching traffic from location of tree on median on outside of left hand bend

Figure A3
Driver's view of trees on median (see Figure A2)

Figure A4 shows a car in which two people died when it struck two trees in the vicinity of the previous crash. The driver was intoxicated.

Figure A4
Final position of part of car following collision with two trees on the median

Figure A5 shows a large tree, which may predate more recent planting, that was struck by a car driven by yet another intoxicated driver, who also died in the crash. Note the wire rope barrier that has since been erected to reduce the risk that a car running onto the median will strike one of the trees.

Figure A5
Large tree on median struck by a car
Wire rope barrier is a recent installation.

The trees struck in the two remaining crashes are not shown here. In one case the tree could no longer be identified accurately and in the other case the road layout at that particular location has been changed substantially.

Apart from the driver of the car which hydroplaned out of control, these drivers had blood alcohol levels ranging from 0.13 to 0.25, most of them near the top of that range. It is therefore not difficult to find reasons for the collisions with the trees. But there are also many other reasons why drivers run off the road. Whatever the reason, as noted in Chapter 7, the penalty should not be death or injury.

Vegetation on the median of a highway can and does play several useful roles. It can act as a shield against oncoming headlights at night, but so would smaller shrubs lacking a substantial main trunk. As illustrated here, trees can prevent an out of control car from crossing into the lanes of oncoming traffic, although that purpose can be achieved in more humane ways, as shown in Figure A5. Shrubs and trees are also attractive. Unfortunately, current planting practices are still similar to those shown here, which demonstrate little regard for the safety of motorists.

APPENDIX B

Appreciating the Danger of Fixed Roadside Hazards

We appear to be born with a fear of heights (Gibson and Walk, 1961), but not with a fear of speed. It may therefore be instructive to think about roadside hazards in another way. As noted in Section 5.3.2, fixed objects such as poles and trees lining the edge of the road in 60 km/h speed limit areas present a similar level of risk of death or injury as having a 14 metre deep sheer drop at the side of the road. This is because the speed of the car on impact with such a hazard is roughly the same as if the car fell 14 metres, or from the top of a 3 story building.

Table B1 shows the equivalent fall distances for a vehicle striking a substantial fixed object at a range of speeds. Travelling at 110 km/h along a tree lined road is comparable to driving at that speed close to the edge of a 47 metre high cliff or, difficult though it may be to imagine, along the top of a 10 story building with nothing to stop the car from going over the edge should there be a momentary lapse of concentration or other interference with the driver's control of the car.

Table B1
The Equivalent Fall Distance for a Vehicle Travelling at the Given Speed which Impacts a Solid Roadside Object

Speed (km/h)	Fall (metres)	Fall (Floors)
10	0.4	0
20	1.6	0
30	3.5	1
40	6.3	1
50	9.8	2
60	14.2	3
70	19.3	4
80	25.2	5
90	31.8	6
100	39.3	8
110	47.6	10
120	56.6	11.3
130	66.4	13.3

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