PATTERNS AND MECHANISMS OF INJURY IN CAR CRASHES

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ABSTRACT

This paper summarises a series of analyses undertaken by the Monash University Accident Research Centre for the Federal Office of Road Safety which set out to identify the extent of damage and injuries to occupants of modern Australian passenger cars. It discusses the difference between active and passive safety and the strengths and weaknesses with existing databases in this state and then presents a systematic analysis of crash and injury patterns that occurred to passenger car occupants during the late 1980s and early 1990s in Victoria. Frontal, side and rollover collisions are emphasised given their relative frequency and severity of injury. A number of priority injuries and source of injury combinations are included to help guide future injury prevention effort.

INTRODUCTION

Injury patterns to car occupants from real-world car crashes are important when determining priorities for new countermeasures as they provide the basis data on the extent, severity and cause of injury. This information is vital for justifying and prioritizing new countermeasures aimed at ameliorating occupant injury as well as providing much needed empirical data on the mechanisms of injury. This latter category is especially important for the design of new countermeasures in particular.

This paper outlines injury patterns on the basis of a number of research studies carried out at the Monash University Accident Research Centre (MUARC) and involves both mass data analyses as well as an in-depth analyses of a sample of real-world crashes involving modern passenger cars. In addition, it discusses a number of allied issues including the strengths and limitations with the various databases available for analysis in this country.

Primary Versus Secondary Safety

Primary and secondary safety is also referred to as ‘active’ and ‘passive’ safety and differentiates between crash and injury prevention. Primary safety relates to crash avoidance (i.e., not having a crash) whereas secondary safety assumes that there is a crash and focusses on preventing the injury. In short, preventing injuries can be achieved by either not having a crash in the first place or by ensuring that any crash is non-injurious to the occupant. These two distinctions are important for directing intervention effort.

In the 1960s, the late William Haddon, an early epidemiologist, first outlined a systematic approach to preventing injuries from road crashes. He noted *three* phases in the prevention of injuries, namely pre-crash, crash and post-crash phases and suggested that interventionists needed to separate elements of the transport system into human, vehicle and the road. More recent expressions of Haddon’s matrix have also added the road environment as a fourth element. An example of Haddon’s matrix and some countermeasures in each of the segments is shown in Figure 1 below.

	Human	Vehicle	Road & Environment
Pre-crash	*drink-drive programs speed reduction aggressive behaviour*	*better handling improved braking increased visibility*	*road engineering black-spot treatments better delineation*
Crash	*wearing seatbelts cycle helmets protective clothing*	*crashworthiness airbags, seatbelts other safety features*	*frangible poles roadside barriers black-spot treatments*
Post-crash	*first-aid knowledge medical details*	*easy access for recovery hospital alarms*	*rapid triage systems rapid alert mechanisms helicopter access*

Figure 1 *The Haddon Matrix showing the different countermeasure approaches.*

The Haddon matrix is really a convenient method of focussing attention on the element of the system and the cause of the problem when designing injury prevention countermeasures. It was the first real attempt at adopting a systematic approach to road safety and has lead to the adoption of a range of countermeasures that have made a substantial contribution to road safety improvement over the last 20 or 30 years.

Mass Data Versus Case Analysis

The two types of databases commonly used for analysing crash patterns and injury types are mass data and case sample data.

Mass databases: The first category, mass databases, usually involve national or state collections such as those regularly collected by the police, the coroner, insurance claims or the health system. In Victoria, databases available for state-wide crash and injury analysis include:

1. Fatality data re-coded from the coroner and in-depth investigation, collated and stored by the Federal Office of Road Safety, the so-called “Fatal File”;
2. Crash details routinely collected by the police on all crashes they attend which is held at VicRoads;
3. Crash, injury and treatment details on all crashes that result in over $500 cost to the Transport Accident Commission, the TAC database; and
4. Hospital in-patient database on all public (and some private) hospital admittance in the state of Victoria.

All of these databases are routine collections for all known road accident cases each year. They have varying degrees of comprehensiveness and crash or injury details as well as different entrance criteria. For the most part, they are more comprehensive for serious crashes and injuries and less reliable (or do not code at all) for minor or non-injurious crashes and thus provide reliable analyses of the type and severity of injury. The police database in NSW has a crash entrance criteria (vehicle was towed from the scene) and this has been a useful source of data for assessing injury involvement rates.

Mass databases are advantaged by the fact that they include all known cases across the state and usually comprise a number of years of crash data. Hence, they include considerable numbers of cases important for statistical analysis and allow for time series analyses. Their biggest disadvantage is usually in the amount of information they contain per case (for instance, police data rarely include detail injuries sustained but rather whether the victim was killed, required hospital attention, injured but did not require hospitalisation or was uninjured). Also, the reliability of these data sometimes comes under question as there are many individuals involved in collecting these data and this can lead to inconsistencies. Moreover, causal analysis is more difficult using these data and analysts are normally only able to report associations between the variables rather than causal statements.

Case Sample Databases: Not surprisingly, then, agencies with a specific interest in injury prevention are forced to collect their own data to ensure that the inherent shortcomings of the mass databases are overcome, predominantly the amount of detail available for analysis. There are three sample databases currently available in this state for road safety analysis, namely:

1. Detailed data collected on a random sample of road crashes in Victoria using the National Accident Sampling System (NASS) format by the Monash University Accident Research Centre, the so-called "*Crashed Vehicle File*" (this databases has details on over 500 passenger car crashes involving more than 600 hospitalised or killed occupants and includes detailed assessments of car damage, crash severity, injuries sustained and cause of each injury);
2. Detailed data collected on a random sample of fatal road crashes in Victoria by the Accident Investigation Squad of the Victorian police (these data are not always freely available as they are often used for legal processing purposes); and
3. A more detailed assessment of cases and causes of injury for people attending a sample of public hospitals in Victoria. These data are collated by MUARC for the Victorian Injury Surveillance System and do permit a more intensive analysis of those attending and admitted to these hospitals that that available in the in-patient database.

These sample databases are particularly useful in that they contain very comprehensive data on both the circumstances of injury, the injuries sustained, and the likely cause of injury. Hence, causal analysis can be undertaken and the number and type of comparison possible is greatly enhanced. However, they do tend to be samples and thus it is not possible to undertake analyses on the extent of crashes or injuries. In addition, as data collection of this kind is costly, the number of cases is generally found to be wanting for detailed statistical breakdowns such as rear seat passengers in frontal crashes of high crash severity.

Thus, it is important when starting out to perform an analysis on patterns of crashes and/or injury to have a clear definition of what is required and the level of statistical reliability necessary before selecting a suitable database for analysis. The outcome can be very much affected by the choice of database. This will be highlighted further in this paper.

PASSENGER CAR CRASH PATTERNS

The crash patterns for passenger car occupant results were originally reported in Fildes, Lane, Lenard and Vulcan (1991) and come from analysis of TAC data for the years up to June 1988. While they are a little old now and crash numbers have reduced dramatically during recent years, the distributions are still expected to be roughly correct.

Type of Crash Configuration

The types of crash configurations that occur in the state of Victoria are shown in Table 1. As discussed above, the proportion of frontal, side, rear-end and rollover crashes will vary depending on the level of severity of the injury sustained, reflected in the various databases used in this analysis. For comparison purposes, similar results from the NSW tow-away are also included in this Table.

***Table 1**: Types of crash configurations in Victoria using various databases available*

Crash Type	***Police Data***	***CVF***	***Fatal File***	***USA - FARS***
Frontal	65%	60%	51%	44%
Side Impact	14%	35%	45%	29%
Rear Impact	11%	0%	2%	3%
Rollover	10%	5%	2%	24%

Data collection periods varied from 1988 to 1992 for these databases.

These results showed the differences propensities for varying crash types to influence outcome severity. Entrance criteria for police data include both injured and uninjured, the Crashed Vehicle File (CVF) hospitalised or killed, while the Fatal File and the US - FARS data were for killed only. The percentage of frontal crashes progressively reduced as outcome severity increased revealing that while these crashes were relatively frequent, they were less critically injurious than other crash types. Conversely, side impacts were more frequent as severity increased illustrating the severe nature of them on car occupants. Of special interest was the large difference in Rollover fatalities between Australian and USA fatal data, suggesting among other things that seatbelt wearing is a very effective means of preventing a fatal outcome in this country.

***Table 2**: Type of crash by outcome severity for occupant claims on the TAC between 1982 and 1988 (from Fildes, Lane, Lenard & Vulcan, 1992).*

Impact	Fatal	Hospitalisation		**Total**	Medical	**Total**
Direction	Injured	>6days	<7days	**Hospital**	Treatment	**Injury**
Frontal	245* *(186)*	938* *(737)*	1,142* *(933)*	**2,080*** ***(1,670)***	5,551 *(6,020)*	**7,876** ***47%***
Side Impact	111* *(99)*	401 *(390)*	448 *(493)*	**849** ***(883)***	3,204 *(3,183)*	**4,164** ***25%***
Rear Impact	7 *(95)*	115 *(374)*	216 *(473)*	**331** ***(847)***	3,661* *(3,057)*	**3,999** ***23%***
Rollover	37* *(21)*	129* *(82)*	198* *(104)*	**327*** ***(186)***	514 *(671)*	**878** ***5%***
Total Victims	**400**	**1,583**	**2,004**	**3,587**	**12,930**	**16,917**

Cell entries show the No. injured occupants at each level of injury outcome.. Figures in parenthesis are the expected values based on row and column totals while the * shows those more than 10% above the expected value.

The results of injury severity by impact direction in Table 2 shows that rollover, frontal, side impact collisions were all over-involved in major injury claims, while rear-end collisions were markedly over-involved in minor (non-hospitalised) injuries.

Type of Vehicle

The vehicle involved in the crash is also likely to have a significant effect on the type of impact as it has been shown that vehicle crashworthiness is a function of vehicle size (see Evans & Wasielewski 1984; Newstead, Cameron & Le, 1997). This is reflected in Table 3 where outcome severity is compared with vehicle size using data collected by the Transport Accident Commission (TAC).

***Table 3**: Size of vehicle by outcome severity for drivers in urban speed crashes (from Fildes, Lane, Lenard & Vulcan, 1991).*

Vehicle Size	Fatal Injured	Hospitalisation >6days	Hospitalisation <7days	**Total Hospital**	Medical Treatment	**Total Injury**
mini-cars *(<750kg)*	6 *(6)*	37* *(24)*	24 *(30)*	**61*** ***(53)***	183 *(191)*	**250** ***1%***
small cars *(<1000kg)*	131 *(167)*	645 *(669)*	845 *(851)*	**1,490** ***(1,520)***	5,484 *(5,023)*	**7,105** ***42%***
compacts *(1001-1250kg)*	186* *(155)*	636 *(620)*	780 *(789)*	**1,416** ***(1,409)***	4,986 *(5,023)*	**6,588** ***38%***
intermediates *(1251-1500kg)*	73* *(66)*	247 *(264)*	351 *(337)*	**598** ***(602)***	2,142 *(2,145)*	**2,813** ***17%***
large *(>1500kg)*	8 *(9)*	49* *(37)*	55* *(47)*	**1.4*** ***(84)***	282 *(300)*	**394** ***2%***
Total	**404**	**1,614**	**2,055**	**3,669**	**13,077**	**17,150**

Cell entries show the No. injured occupants at each level of injury outcome.. Figures in parenthesis are the expected values based on row and column totals while the * shows those more than 10% above the expected value.

While there is some suggestion that occupants of smaller vehicles may be over-represented in severe injury crashes, the 3 larger sized vehicles also tended to be over-represented in fatal and longer hospital admissions, contrary to expectations. This finding is likely to be confounded with other influences (e.g., speed of the crash, age of the occupant, crash type, seating position, etc.). Indeed, closer examination revealed that occupants of small cars (especially mini-sized vehicles) were over-represented in urban crashes, equal to or less than 75km/h posted speed, while intermediate and large car occupants were over-represented in higher speed (>75km/h) rural crashes.

Age and Sex of the Occupant

Table 4 shows that children aged below 17 years and older adults, 56 years and above were over-represented as injured occupants in road crashes. Moreover, children were more likely to be injured in large cars, young adults (those 17 to 25 years) were over-represented as injured occupants from small vehicles, adults aged 26 to 55 years were over-involved in intermediate and large vehicle crashes, while the very old (those aged greater than 75 years) were more likely to have come from mini and small passenger cars. These results reflect differences in both usage patterns and occupant frailty amongst the motoring population.

Table 4*: Occupant age by outcome severity for occupant claims on the TAC between 1982 and 1988 (from Fildes, Lane, Lenard & Vulcan, 1991).*

Occupant	Fatal	Hospitalisation		**Total**	Medical	**Total**
Age	Injured	>6days	<7days	**Hospital**	Treatment	**Injury**
<17 years	38* *(31)*	81 *(123)*	211* *(157)*	**302*** ***(280)***	979 *(1,009)*	**1,319** ***7%***
17-25 years	105 *(108)*	333 *(433)*	533 *(552)*	**866** ***(985)***	3,671 *(3,549)*	**4,642** ***26%***
26-55 years	162 *(213)*	773 *(858)*	1,004 *(1,094)*	**1,777** ***(1,952)***	7,257 *(7,031)*	**9,196** ***51%***
56-75 years	81* *(62)*	410* *(250)*	360* *(319)*	**770*** ***(569)***	1,830 *(2,050)*	**2,681** ***15%***
>75 years	35* *(8)*	98* *(31)*	44* *(40)*	**142*** ***(71)***	158 *(256)*	**335** ***2%***
Totals	**421**	**1,695**	**2,162**	**3,857**	**13,895**	**18,173**

Cell entries show the No. injured occupants at each level of injury outcome.. Figures in parenthesis are the expected values based on row and column totals while the * shows those more than 10% above the expected value.

Differences in the sex of occupants by injury outcome was examined in Table 5 where males were clearly over-represented in serious injury claims. Furthermore, the larger the passenger car, the more likely the injured occupant was a male. Females did make up a surprising 59% of the total number of injured occupants recorded by the TAC which is noticeably higher than their licensing rates (46%, Vic Roads 1990) or the population at large (51%, ABS 1990).

Table 5*: Occupant sex by outcome severity for occupant claims on the TAC between 1982 and 1988 (from Fildes, Lane, Lenard & Vulcan, 1991).*

Occupant	Fatal	Hospitalisation		**Total**	Medical	**Total**
Sex	Injured	>6days	<7days	**Hospital**	Treatment	**Injury**
Female	171 *(248)*	943 *(997)*	1,155 *(1,271)*	**2,098** ***(2,268)***	8,429* *(8,180)*	**10,698** ***59%***
Male	251* *(174)*	753* *(698)*	1,007* *(890)*	**1,760*** ***(1,588)***	5,478 *(5,726)*	**7,489** ***41%***
Total	**422**	**1,696**	**2,162**	**3,858**	**13,907**	**18,187**

Cell entries show the No. injured occupants at each level of injury outcome.. Figures in parenthesis are the expected values based on row and column totals while the * shows those more than 10% above the expected value.

Seating Position

The findings of outcome severity by seating position within the car are shown in Table 6 which show that drivers were under-represented in a severe outcome compared to all other seating positions.

***Table 6**: Seating position by outcome severity for occupant claims on the TAC between 1982 and 1988 (from Fildes, Lane, Lenard & Vulcan, 1991).*

Seating Position	Fatal Injured	Hospitalisation >6days	Hospitalisation <7days	**Total Hospital**	Medical Treatment	**Total Injury**
driver	248 *(252)*	965 *(1,020)*	1,185 *(1,320)*	**2,150** ***(2,340)***	8,713 *(8,518)*	**11,111** ***62%***
front-left	89 *(96)*	433* *(389)*	566* *(504)*	**999*** ***(893)***	3,152 *(3,251)*	**4,240** ***25%***
rear outboard	54* *(43)*	176 *(174)*	281* *(225)*	**457*** ***(399)***	1,381 *(1,450)*	**1,892** ***11%***
rear centre	7 *(7)*	40* *(30)*	56* *(38)*	**96*** ***(68)***	218 *(246)*	**321** ***2%***
Totals	**398**	**1,614**	**2,087**	**3,700**	**13,464**	**17,564**

Cell entries show the No. injured occupants at each level of injury outcome.. Figures in parenthesis are the expected values based on row and column totals while the * shows those more than 10% above the expected value.

Previous studies have shown that males are more likely to be drivers, females front seat passengers, and children rear seat occupants (Rogerson and Keall 1990; Fildes, Rumbold & Leening, 1991). In addition, there is a strong belief that younger adults are more likely to be drivers than older adults. These findings, therefore are likely to be influenced by the age and sex of the occupant as well as the size of vehicle.

Seatbelt Wearing

Seat belt wearing information is routinely collected by the police investigating crashes. However, they are only rarely able to make a direct observation of whether the occupant was wearing a seatbelt or not and for the most part are forced to rely on self-reports or witness accounts. These accounts are therefore highly unreliable, evidenced by the high incidence figures in the TAC database (98% of front seat occupants were supposedly wearing their seatbelt at the time of their crash from police reports which is even higher than the 94% observed wearing rate among the population at large at that time).

A more accurate method of assessing seatbelt wearing is to undertake an in-depth analysis of the crashed vehicle looking for stretch marks and signs of loading on the belt itself after the crash. This procedure has been fully described by Cromark, Schneider & Blaisdell, 1990). A small comparative examination was carried out of seat belt wearing for the same cases as reported on police accident reports and from a detailed examinations of the belts in the crashed vehicle sample. These results are shown in Table 7 and reveal a 12% over-reporting rate of seat belt use by police for those hospitalised from road crashes.

Of specific interest, also, non-wearing rates of seatbelts among the injured population when assessed from the vehicle was 16% or approximately three times higher than the population levels at that time (6%). This clearly shows the benefit of the seatbelt in protecting occupants from injury, although it may also suggest that non-wearers of seatbelts are also more likely to be involved in crashes as well.

Table 7 *Seatbelt wearing rates by inspection and police accident reports (from Fildes, Lane, Lenard & Vulcan, 1991)*

	Investigator's Account		
Police Account	*Wearing*	*Non-wearing*	***TOTAL***
Wearing	90 *(83%)*	13 *(12%)*	**103** ***(95%)***
Non-wearing	1 *(1%)*	5 *(4%)*	**6** ***(5%)***
TOTAL	**91** ***(84%)***	**18** ***(16%)***	**109**

Speed of the Crash

Mass databases do not record the speed of impact of the vehicle as this information is not readily available. However, the delta-V of the crashed car was computed for each case in the Crashed Vehicle File where it could be calculated using the CRASH3 program produced by the National Highway Traffic Safety Administration in Washington DC. While these values have been criticised as not being totally reliable, nevertheless, they do provide a measure of impact severity more robust that simply the speed zone where the crash occurred. The distribution of impact severity for frontal and side impacts is shown in Figures 2 and 3.

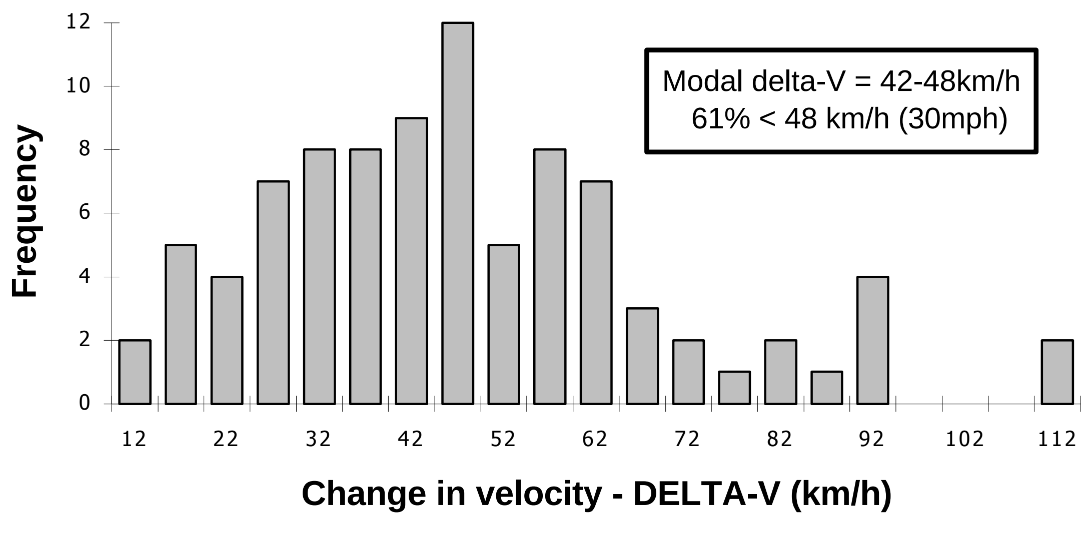

Figure 2 *Frequency histogram of impact velocities (delta-V) observed for the frontal crash sample (from Fildes, Lane, Lenard & Vulcan, 1991)*

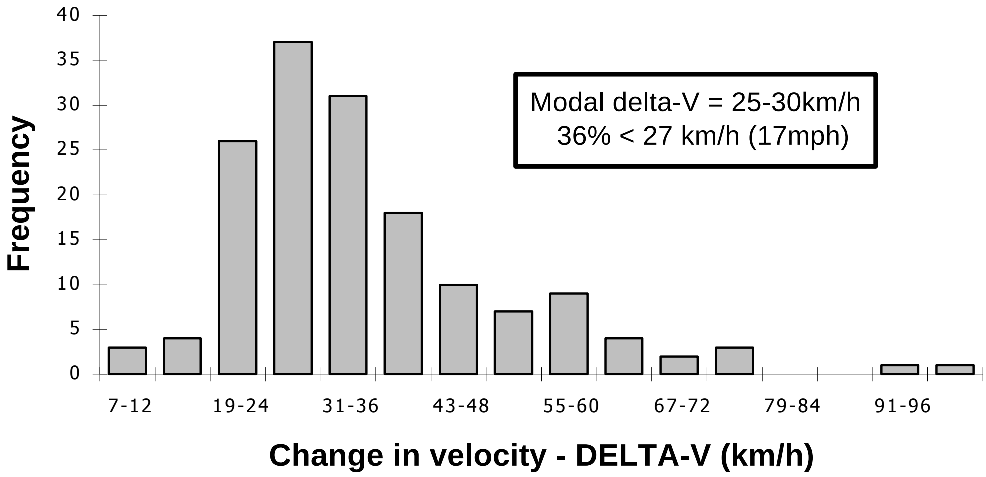

Figure 3 *Frequency histogram of impact velocities (delta-V) observed for the side impact crash sample (from Fildes, Lane, Lenard & Vulcan, 1994)*

ANALYSIS OF OCCUPANT INJURIES

The analysis of occupant injuries comes predominantly from the Crashed Vehicle File held at MUARC as these data provide the best account of the type of injury, severity of injury and causes of injury from both inside and outside the vehicle during a crash. Given the fact that different types of crashes result in different types of injuries, this paper will examine a select number of occupant injury patterns found in front, side and rollover crashes.

Frontal Crashes

A full analysis of passenger car occupant injuries in frontal crashes was reported in Fildes, Lane, Lenard and Vulcan (1991) and those interested in a more detailed analysis should consult this publication.

Table 8 *Seating position by severity and the probability of sustaining a severe injury in a frontal crash (adapted from Fildes, Lane, Lenard & Vulcan, 1991)*

Seating Position	Number Occupants	Average ISS*	Probability of a severe injury		
			AIS>2	ISS>15	ISS>25
driver	167	17.9	62%	50%	19%
front-left	66	17.0	58%	45%	24%
rear outboard	24	13.9	56%	25%	8%
rear centre	6	11.3	40%	16%	0%
Total (Averages)	**263**	**(17.8)**	**(60%)**	**(46%)**	**(19%)**

ISS - Injury Severity Score is a generally accepted measure of overall severity (Baker et al 1980) and is calculated by adding the square of the 3 highest AIS scores for 3 separate body regions.

Table 9 *Body region injuries sustained in frontal crashes (adapted from Fildes, Lane, Lenard & Vulcan, 1991)*

Body Region Injured	**Drivers (n=167)**		**Front Left (n=66)**		**Rear (n=34)**	
	ALL	**AIS>2**	**ALL**	**AIS>2**	**ALL**	**AIS>2**
Head	61%	*18%*	48%	*12%*	35%	*18%*
Face	67%	*4%*	50%	*2%*	44%	-
Chest	67%	*26%*	70%	*26%*	56%	*26%*
Abdomen	42%	*6%*	44%	*9%*	65%	*26%*
Pelvis	29%	*10%*	33%	*12%*	24%	*3%*
Upper limbs	68%	*10%*	47%	*11%*	56%	*12%*
Knee & thigh	53%	*10%*	30%	*8%*	24%	*9%*
Lower limbs	43%	*16%*	38%	*5%*	38%	-
Spine	25%	*4%*	27%	*9%*	44%	*3%*
Average/patient	**4.5**	***1.0***	**3.9**	***0.9***	**3.9**	***1.0***

Figures for ALL injuries refer to the percent of patients who sustained a particular body region injury of any severity while those in parenthesis show the percentage of severe injuries (AIS greater than 2). Entrance criteria for the CVF dictated that at least one occupant was either hospitalised or killed in the crash.

Table 10 *Source of injury observed for occupants injured in frontal crashes (adapted from Fildes, Lane, Lenard & Vulcan, 1991)*

Body Region Injured	**Drivers (n=167)**		**Front Left (n=66)**		**Rear (n=34)**	
	ALL	**AIS>2**	**ALL**	**AIS>2**	**ALL**	**AIS>2**
w'screen & header	16%	*1%*	20%	*5%*	6%	*3%*
steering wheel	53%	*19%*	-	-	-	-
steering column	10%	*4%*	-	-	-	-
Instrument panel	49%	*12%*	41%	*17%*	-	-
console	8%	-	2%	-	12%	-
A,B & C pillars	7%	*5%*	9%	*3%*	3%	-
side glazing	7%	*2%*	9%	-	6%	*3%*
door panel & rail	28%	*19%*	46%	*24%*	32%	*18%*
roof surface	4%	*4%*	8%	-	-	-
seats	1%	-	2%	-	35%	*6%*
seat belts	49%	*7%*	46%	*6%*	44%	*12%*
other occupants	3%	*1%*	6%	*3%*	3%	-
floor & toe pan	25%	*8%*	12%	*3%*	3%	-
exterior objects	8%	*2%*	11%	*6%*	15%	*15%*
non-contacts	25%	-	21%	*5%*	27%	*3%*
Average/patient	**3.9**	***0.9***	**3.3**	***0.8***	**2.9**	***0.6***

Figures for ALL injuries refer to the percent of patients who sustained a particular body region injury of any severity while those in parenthesis show the percentage of severe injuries (AIS greater than 2). Entrance criteria for the CVF dictated that at least one occupant was either hospitalised or killed in the crash.

Table 11 *Six injury prevention priorities for occupants involved in frontal crashes (adapted from Fildes, Lane, Lenard & Vulcan, 1991)*

Drivers		Front Left Passengers		Rear Passengers	
chest with steering	12%	upper limb with dash	11%	abd. with seatbelt	21%
lower leg with floor	11%	chest with seatbelt	11%	chest with seatbelt	11%
head with steering	10%	thigh/knee with dash	8%	head with windscreen	5%
thigh.knee with dash	10%	lower leg with floor	5%	upper limb with door	5%
chest with seatbelt	6%	chest with dash	5%	thigh/knee with door	5%
face with steering	6%	pelvis with dash	5%	thigh/knee with seats	5%

Priorities based on the most frequent severe (AIS>2) injury and source of injury combinations observed in the CVF. Entrance criteria for the CVF dictated that at least one occupant was either hospitalised or killed in the crash.

Summary: In summary, drivers injured in frontal crashes had slightly more injuries than either front left or rear seat passengers and had a higher probability of sustaining a severe injury. Rear seat passengers hospitalised or killed in frontal crashes were relatively less injured. Severe injuries to the chest and head, and lower limbs were especially problematic for front seat occupants while drivers sustained a substantial number of lower limb injuries too. Sources of severe injury to these occupants included the steering wheel (for drivers) and the instrument and door panels. The seatbelt was especially pronounced among severe chest injuries to rear seat occupants suggesting these layouts require urgent attention. A range of priority injury and source combinations were identified that need to be focussed on in future intervention efforts.

SIDE IMPACT CRASHES

A full detailed analysis of passenger car occupant injuries in side impact crashes was reported in Fildes, Lane, Lenard and Vulcan (1994) and is summarised below.

Table 12 *Seating position by severity and the probability of sustaining a severe injury in a side impact crash (adapted from Fildes, Lane, Lenard & Vulcan, 1994)*

Seating Position	Number Occupants	Average ISS*	Probability of a severe injury		
			AIS>2	ISS>15	ISS>25
driver	141	29.6	76%	70%	48%
front-left	62	30.1	77%	69%	35%
rear	31	34.5	74%	61%	42%
Total (Averages)	**234**	**(30.4)**	**(76%)**	**(69%)**	**(44%)**

ISS - Injury Severity Score is a generally accepted measure of overall severity (Baker et al 1980) and is calculated by adding the square of the 3 highest AIS scores for 3 separate body regions. Entrance criteria for the CVF dictated that at least one occupant was either hospitalised or killed in the crash.

Table 13 *Body region injuries sustained in a side imapct crash (adapted from Fildes, Lane, Lenard & Vulcan, 1994)*

Body Region Injured	Drivers (n=141)		Front Left (n=62)		Rear (n=31)	
	ALL	AIS>2	ALL	AIS>2	ALL	AIS>2
Head	70%	*26%*	65%	*24%*	52%	*13%*
Face	60%	*1%*	48%	-	65%	-
Chest	67%	*29%*	77%	*39%*	58%	*32%*
Abdomen & pelvis	70%	*16%*	76%	*18%*	48%	*19%*
Upper limbs	67%	*5%*	47%	*3%*	68%	*16%*
Lower limbs	54%	*12%*	48%	*6%*	45%	*3%*
Spine & neck	26%	*4%*	26%	*15%*	32%	*3%*
Average/patient	**5.0**	***1.9***	**4.9**	***2.0***	**4.6**	***1.8***

Figures for ALL injuries refer to the percent of patients who sustained a particular body region injury of any severity while those in parenthesis show the percentage of severe injuries (AIS greater than 2). Entrance criteria for the CVF dictated that at least one occupant was either hospitalised or killed in the crash.

Table 14 *Source of injury observed for occupants injured in side Impact crashes (adapted from Fildes, Lane, Lenard & Vulcan, 1994)*

Body Region Injured	Drivers (n=141)		Front Left (n=62)		Rear (n=31)	
	ALL	AIS>2	ALL	AIS>2	ALL	AIS>2
w'screen & header	2%	*1%*	3%	-	-	-
steering assy	14%	*4%*	2%	-	-	-
Instrument panel	34%	*4%*	26%	*2%*	3%	*3%*
console	6%	*1%*	3%	-	-	-
A-pillar	5%	*1%*	6%	*2%*	-	-
B-pillar	6%	*3%*	15%	-	3%	-
C-pillar	1%	-	-	-	3%	-
Side door panel	71%	*28%*	84%	*34%*	55%	*23%*
roof side rail	1%	-	2%	-	3%	*3%*
roof surface	6%	*4%*	2%	-	3%	*3%*
seats	3%	-	3%	-	10%	-
seat belts	35%	*3%*	35%	*3%*	16%	-
other occupants	10%	*3%*	16%	*11%*	3%	*3%*
floor & toe pan	11%	*2%*	8%	*3%*	3%	-
exterior objects	23%	*11%*	24%	*10%*	39%	*3%*
non-contacts	38%	*1%*	31%	*10%*	26%	-
Average/patient	**3.8**	***1.7***	**3.8**	***1.7***	**2.9**	***1.4***

Figures for ALL injuries refer to the percent of patients who sustained a particular body region injury of any severity while those in parenthesis show the percentage of severe injuries (AIS greater than 2). Entrance criteria for the CVF dictated that at least one occupant was either hospitalised or killed in the crash.

Table 15 *Six injury prevention priorities for occupants involved in side impact crashes (adapted from Fildes, Lane, Lenard & Vulcan, 1994)*

Near-side Occupants		**Far-side Occupants**	
chest with near-side door	38%	chest with other occupant	10%
Abd-pelvis with near door	18%	chest with far-side door	9%
head with exterior object	12%	abd-pelvis with seatbelt	7%
lower limb with near door	7%	head with exterior object	7%
lower limb with dash	4%	head with other occupant	6%
lower limb with floor	3%	head with far-side door	4%

Priorities based on the most frequent severe (AIS>2) injury and source of injury combinations observed in the CVF. Entrance criteria for the CVF dictated that at least one occupant was either hospitalised or killed in the crash. Near-side and far-side occupants include both front and rear seat passengers adjacent or opposite the impact side.

Summary: In summary, drivers sustained marginally more injuries on average than all other occupants. However, there were practically no differences observed in the severity of these injuries across all seating positions. Severe injuries to the chest, head and abdomen and pelvis were observed for all occupants regardless of their seating position. These injuries are more likely to be life threatening than others confirming the serious nature of these crashes for occupants. The average level of injury severity (ISS) for this sample was almost twice that found in similar frontal crashes. The most common sources of injury to both front and rear occupants was the door panel and frame. Other injury sources were the side panel, instrument panel, and side window. While seat belts caused injury to approximately one-third of the occupants, these injuries were predominantly minor.

Other occupants caused severe injuries most noticeably to front left passengers. This was, in part, because there is always another occupant (the driver) present. Exterior objects were more frequently a source of injury for rear seat passengers reflecting the higher non-wearing behaviour and the greater tendency for ejection in the rear seat. A range of injury and source combinations were identified as priority issues for increased side impact protection.

ROLLOVER COLLISIONS

Collisions involving vehicle rollover are not particular frequent types of road crashes (10% of hospitalised TAC claims and 5% of patients in the crashed vehicle study). However, they do tend to result in very severe and disabilitating injury to the occupants involved in these collisions, and injury interventions are likely to be different for rollovers, compared to other crash types.

A relatively small analysis of passenger car occupant injuries in rollover crashes was reported in Fildes, Lane, Lenard and Vulcan (1991) and is repeated here. The number of cases was small (11 and 12 cases respectively), therefore this analysis should only be considered preliminary at this stage.

Rollover configurations

Figure 4 shows the various types or extents of rollovers observed in the crashed vehicle sample to date. Of the cases where rollover extent could be assigned, most were full turns or more or end-to-end, compared to only partial rollovers.

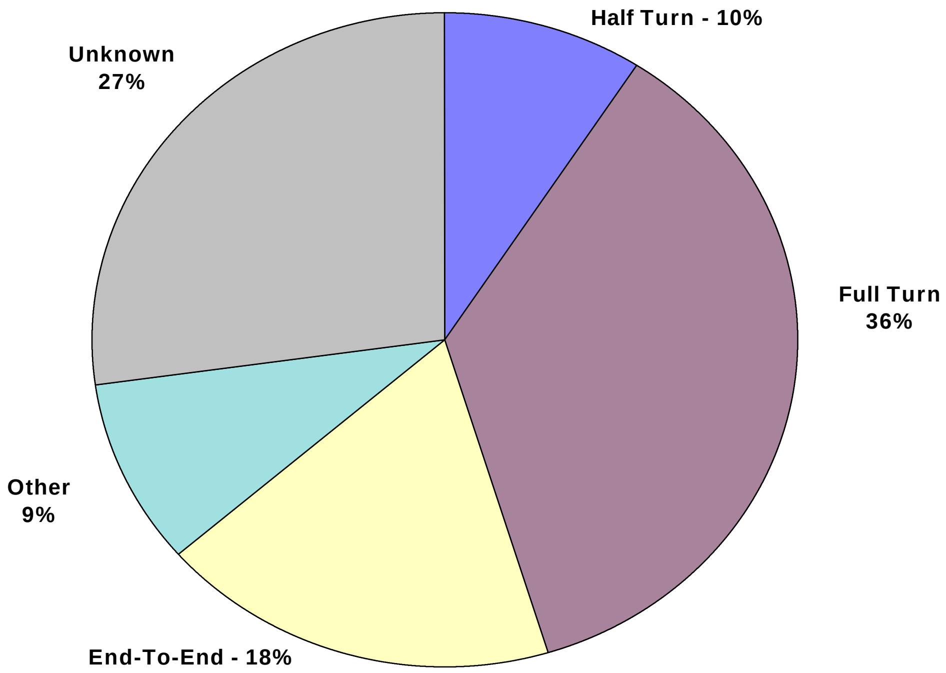

Figure 4 *Extent of vehicle rollover observed in the crashed vehicle sample at this time.*

Intrusions and Deformations

Table 16 lists the rank ordering of component intrusions into the front and rear seat occupant areas for the sample of rollover collisions (intrusion is once more defined in relation to the space inside the vehicle likely to be occupied by passengers). As previously recorded for other crash types, there were more intrusions in the front than the rear seat passenger compartment (3.0 cf. 1.7 per crash). By far, the most common intrusions observed in these crashes were from the vehicle roof and roof structure. In addition, there were a sizable number of intrusions also from the roof supports (the A-, B-, and C-pillars).

Table 16*: Rank ordering of vehicle intrusions in rollover collisions by front and rear seating areas (from Fildes, Lane, Lenard & Vulcan, 1991)*

Front Seat Intrusions		Rear Seat Intrusions	
Item	**Frequency**	**Item**	**Frequency**
Roof	127%	Roof	109%
Roof side rail	55%	Roof side rail	27%
A-pillar	46%	C-pillar	18%
Windscreen & header	36%	B-pillar	9%
B-pillar	27%	Side panel	9%
Steering assembly	9%		

Ejections and Entrapments

The number of occupants who were ejected or entrapped in their vehicles in rollovers is shown in Tables 17 and 18. Because of the very small numbers of cases in each category, one should not make too much of these results at this time.

***Table 17**: Ejection analysis for belted and unbelted occupants in rollover crashes (from Fildes, Lane, Lenard & Vulcan, 1991)*

Ejections	Belted Frequency	Unbelted Frequency
No ejection during rollover	84%	67%
Occupant fully ejected	-	33%
Occupant partially ejected	-	-
Unknown	16%	-
Total	**100%**	**100%**

Ejection status is a difficult assessment retrospectively as it requires self-reports or witness accounts. Cases = 9.

***Table 18**: Entrapment analysis for belted and unbelted occupants in rollover crashes (from Fildes, Lane, Lenard & Vulcan, 1991)*

Entrapments	Belted Frequency	Unbelted Frequency
No entrapment during rollover	84%	67%
Occupant fully entrapped	-	33%
Occupant partially entrapped	-	-
Unknown	16%	-
Total	**100%**	**100%**

Entrapment status is a difficult assessment retrospectively as it requires self-reports or witness accounts. Cases = 9.

Injury and Source Analysis

Table 19 shows the injury by source of injury analysis for the 12 occupants who were killed or hospitalised from rollover collisions in this study. In order of frequency, the body regions injured included the upper extremity, head, face, spine, and chest, while for severe (AIS>2) injuries, they were the head, chest, and the spine. The main points of contact for occupants in rollovers were the roof, exterior objects, the door panels, and side glazing. There was a sizable number of injuries for which a point of contact could not be identified in these crashes.

***Table 19:** Body region by source of injury for all and severe injuries for the 12 occupants injured in a rollover collision (from Fildes, Lane, Lenard & Vulcan, 1991)*

Contact source		***Head***	***Face***	***Chest***	***Abdomen***	***Pelvis***	***Upper leg***	***Thigh/knee***	***Lower leg***	***Spine***	***TOTAL***
Windshield & header	ALL	8					17				**25**
	AIS>2										**0**
Steering assembly	ALL				8						**8**
	AIS>2										**0**
Steering column	ALL										**0**
	AIS>2										**0**
Instrument panel	ALL										**0**
	AIS>2										**0**
Console	ALL										**0**
	AIS>2										**0**
Pillars	ALL										**0**
	AIS>2										**0**
Side glazing	ALL	25	33								**58**
	AIS>2	17									**17**
Door panel	ALL						42		8	8	**58**
	AIS>2										**0**
Roof surface	ALL	42	17							17	**76**
	AIS>2	17									**17**
Seats	ALL										**0**
	AIS>2										**0**
Seat belt	ALL			17	8		8			17	**50**
	AIS>2										**0**
Other occupant	ALL										**0**
	AIS>2										**0**
Floor	ALL										**0**
	AIS>2										**0**
Exterior	ALL	17	8	8	8		17			8	**66**
	AIS>2	8		8	8						**24**
Non-contact	ALL		8				8	8		8	**32**
	AIS>2									8	**8**
Other/unknown	ALL	25	8	17	8	8	42				**108**
	AIS>2	8		17							**25**
TOTAL	***ALL***	***117***	***74***	***42***	***32***	***8***	***134***	***8***	***8***	***58***	***481***
	AIS>2	***50***	***0***	***25***	***8***	***0***	***0***	***0***	***0***	***8***	***91***

Top row figures are the injury/source contact rates per 100 occupants for ALL levels of injury. The lower line figures are the contact rates for severe injuries only (AIS>2). Multiple injuries are included where separate injury/sources are involved.

The most noteworthy injury and source of injury combinations for all occupants in rollover crashes are shown in Table 20 below. While these suggests priorities for injury prevention in this crash configuration, they should only be taken as preliminary suggestions, given the small amount of data available in this analysis.

Table 20 *Six preliminary injury prevention priorities for occupants involved in rollover crashes (from Fildes, Lane, Lenard & Vulcan, 1991)*

Injury by Contact Source	Frequency
Head with the roof surface	17%
Head with side glazing	17%
Head with exterior object	8%
Chest with exterior object	8%
Abdomen with exterior object	8%

Priorities based on the most frequent severe (AIS>2) injury and source of injury combinations observed in the CVF. Entrance criteria for the CVF dictated that at least one occupant was either hospitalised or killed in the crash.

Rollover Summary

The results of the rollover analysis are very restricted because of the very few cases involved at this time. Like the side impact analysis, care needs to be taken in inferring very much from these preliminary findings. Full turn and end-to-end were more common than partial turn roll-over configurations amongst the sample. It was not possible to measure impact velocity for these crashes using CRASH 3.

There were more intrusions in the front than the rear passenger compartment. The roof and its structural members were the major source of intruding mechanisms in these vehicles. There were too few cases to infer anything meaningful from the entrapment and ejection analyses.

The head, chest, and spine featured amongst the severe injuries incurred by these occupants. Contacts with the roof, door panel, side glazing and the exterior were most common in rollover collisions. It should be noted that the source of injury for a sizable proportion of body region injuries (including both all and severe injuries) could not identified in these crashes.

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