VEHICLE CRASHWORTHINESS RATINGS IN AUSTRALIA

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ABSTRACT

The paper reviews the published vehicle safety ratings based on mass crash data from the United States, Sweden and Great Britain. It then describes the development of vehicle crashworthiness ratings based on injury compensation claims and police accident reports from Victoria and New South Wales, the two largest States in Australia.

Crashworthiness was measured by a combination of injury severity (of injured drivers) and injury risk (of drivers involved in crashes). Injury severity was based on 22,600 drivers injured in crashes in the two States. Injury risk was based on 70,900 drivers involved in crashes in New South Wales where a vehicle was towed away. Injury risk measured in this way was compared with the "relative injury risk" of particular model cars involved in two car crashes in Victoria (where essentially only casualty crashes are reported), which was based on the method developed by Folksam Insurance in Sweden from Evan's double-pair comparison method.

The results include crashworthiness ratings for the makes and models crashing in Australia in sufficient numbers to measure their crash performance adequately. The ratings were normalised for the driver sex and speed limit at the crash location, the two factors found to be strongly related to injury risk and/or severity, and to vary substantially across makes and models of Australian crash-involved cars. This allows differences in crashworthiness of individual models to be seen, uncontaminated by major crash exposure differences.

ACKNOWLEDGEMENT AND DISCLAIMER

This paper is based on a Monash University Accident Research Centre technical report which used information supplied by VIC ROADS, the Transport Accident Commission in Victoria, the Roads and Traffic Authority in New South Wales, the Royal Automobile Club of Victoria, and the National Roads and Motorists' Association. The paper may only be reproduced in its entirety. Any republication of the findings of this paper whether by way of summary or reproduction of the tables or otherwise is prohibited unless prior written consent is obtained from the Monash University Accident Research Centre and any conditions attached to that consent are satisfied.

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INTRODUCTION

There is a need to inform consumers of the relative safety of cars offered for sale as a way of encouraging manufacturers to improve the crash performance of their products (Social Development Committee 1990; Dowdell 1990a, 1990b). Consumer advice on vehicle safety performance can provide vehicle make/model ratings of two types:

- Crashworthiness ratings (measuring the relative safety of vehicles in preventing injury and/or severe injury in crashes)
- Crash involvement ratings (measuring attributes which assist or prevent vehicles from being involved in crashes).

Previous research has shown that vehicle factors play a large role in whether a car occupant is severely injured in a crash (other key factors are the impact speed, point of impact, seating position, restraint use, and the occupant's age and sex). International evidence shows that there are considerable differences between makes and models related to vehicle crashworthiness (Campbell and Reinfurt 1973; Gustafsson et al 1989).

In contrast, vehicle factors have been estimated in several studies (summarized by Johnston 1984) to be the cause of about 10% of crash involvements (road user factors cause about 90% and environmental factors cause about 30%; multiple causes are common). Thus there is much less potential for make/model differences related to crash involvement.

The development of crashworthiness ratings should be given priority in vehicle safety ratings because of their greater potential to find significant differences between makes and models of cars.

This paper summarizes the data and analysis methods used in a Monash University Accident Research Centre project to develop crashworthiness ratings and presents ratings for 1982-90 model vehicles based on crash data from Victoria and New South Wales (NSW) combined. Further details are given in the technical report from the project (Cameron et al 1992) which covers the concepts developed, preparation of the data used, preliminary investigations to determine analysis methods, details of the adjustment procedures, and investigations of the separate results from Victoria and NSW.

LITERATURE REVIEW

Vehicle safety ratings based on mass crash data have been published as consumer advice by the Highway Safety Research Centre (Campbell and Reinfurt 1973), the Insurance Institute for Highway Safety (IIHS 1991), and the Highway Loss Data Institute (HLDI 1991) in the USA; Folksam Insurance (Gustafsson et al 1989; Folksam, undated) in Sweden; and the UK Department of Transport (DOT 1991). These are summarised in Table 1 and detailed reviews are given elsewhere (Cameron 1991, Cameron et al 1992). Vehicle safety ratings based on sources other than mass crash data have also been published, such as those using results from barrier crash tests (Gillis 1991) or from assessments of the presence of a number of occupant protection features in each model (Vehicle Safety Consultants 1989).

The five published vehicle safety ratings based on mass crash data have each used different measures of vehicle safety performance. While the general tendency is for the measures to cover crashworthiness aspects (perhaps reflecting a perception that the biggest differences between cars should emerge in this dimension), many of the measures embody the risk of crash involvement as well. Only the vehicle safety ratings published by the Highway Safety Research Centre and by Folksam Insurance can be considered to measure crashworthiness exclusively.

Table 1: Summary of published vehicle safety ratings based on mass crash data.

Publishing organisation	Rating measures used in the publication	Dimensions covered by the measure: . Crash involvement (CI) . Crashworthiness (CW)	Factors used to adjust the ratings before comparison between models	Factors used to categorize the [adjusted] ratings into car groups
Highway Safety Research Centre (USA)	Rate of driver death or serious injury per involvement in crashes with damage exceeding $100	CW	Impact speed Point of impact on car Accident type	Crash type (single-vehicle versus car-to-car crashes)
Insurance Institute for Highway Safety (USA)	Occupant death rate per 10,000 registered cars	CI and CW	Car wheelbase Driver age Driver sex	Car wheelbase Body style
Highway Loss Data Institute (USA)	1. Occupant injury rate per insured vehicle year a) any injury b) injury costs > $500 2. Vehicle damage payments per insured vehicle year	1. CI and CW 2. CI	1. Driver age 2. Driver age Deductible amount (excess)	Car wheelbase Body style
Folksam Insurance (Sweden)	1. Relative risk of driver injury in two-car crashes 2. Risk of death or permanent disability to occupants who were injured 3. Combination: 1 by 2	1. CW 2. CW 3. CW	1. Car weight (contra to weight of "other" car) 2. Nil 3. Car weight (see above)	Car weight
Department of Transport (UK)	1. Injury accident involvement rate per 10,000 registered cars 2. Car occupant casualty rate per 10,000 registered cars 3. Driver casualty rate per 100 accidents involving impact with another vehicle or other hard object	1. CI and CW 2. CI and CW 3. CW	Nil	Age of car Performance of car Size of car Owner of car (private or company)

In some cases the organisations appear to recognise that their measure includes crash involvement risks, and they take steps to correct the differences in risk between models by adjusting or categorizing their vehicle ratings by factors such as driver age and sex and the type of car (eg. body style, age, performance, and whether privately or company owned). It is usually not known or not stated whether these factors adequately account for the differences in crash involvement risk. It is possible that the vehicle safety ratings published by IIHS, HLDI, and the UK DOT continue to reflect differences in driver types and usage patterns as well as differences in crashworthiness between the models of cars which they compare.

CRASH DATA USED

Victorian Crashes

Detailed injury data have been collected by the Transport Accident Commission (TAC) and its predecessor, the Motor Accidents Board, as part of their responsibilities to provide road transport injury compensation in Victoria. Details of the vehicle occupied were added from the VIC ROADS vehicle registration system.

TAC claims from drivers of cars and station wagons manufactured after 1981 who were involved in crashes in the period 1983 to 1990, and whose medical expenses exceeded a threshold which was indexed from year to year ($317 in 1989), were matched with Police accident reports. The Police reports were on all drivers involved in accidents, no matter whether the Police officer recorded the person as injured or uninjured (it was possible for an injury claim to be made in circumstances where injury was not apparent at the time of the accident). Accidents are reported to the Police in Victoria if a person was killed or injured, if property was damaged but names and addresses were not exchanged, or if a possible breach of the Road Traffic Regulations has occurred (Green 1990).

The merged file covered 15876 drivers of 1982-90 model cars and station wagons crashing during 1983-90. Of these drivers involved in reported crashes, 12867 (81%) were injured (ie. TAC claimants), and 3158 (24.5%) of the injured were killed or hospitalised.

New South Wales Crashes

The NSW Roads and Traffic Authority (RTA) supplied a file covering 75860 light passenger vehicles involved in Police reported crashes during 1989-90 which resulted in death or injury or a vehicle being towed away. The National Roads and Motorists' Association (NRMA) had added the make, model and year of manufacture to these vehicles after matching with the NSW vehicle register via registration number. The file supplied covered vehicles manufactured during the period 1982-90. The file not only covered cars and station wagons, but also covered four-wheel drive vehicles, passenger vans, light trucks and other commercial vehicles (these could be identified by their model).

The vehicle file (which also contained driver age and sex) was merged with files supplied by NSW RTA covering details of the person casualties (killed and injured persons) and the reported crashes for the same years. Each vehicle/driver matched uniquely with the corresponding crash information, but only injured drivers could match with persons in the casualty file. A driver who did not match was considered to be uninjured. When the unoccupied vehicles were excluded, the injury details of 73399 drivers involved in crashes were available. According to the data supplied about these drivers, 10097 (13.8%) were injured and 2045 (20.3%) of the injured were killed or hospitalised.

The presence of uninjured drivers in the merged data file meant that it was suitable for measuring the risk of driver injury (in cars sufficiently damaged to require towing). This contrasted with the Victorian data file, which could not be used to measure injury risk directly because not all uninjured drivers were included.

DERIVATION OF MODELS OF CARS

The Victorian vehicle register provided the make and year of manufacture of the crashed vehicle but not the model. Model was initially derived for 1982-88 model cars using logic developed and supplied by the Royal Automobile Club of Victoria (RACV) based on the make, year and power-mass units. Power-mass units (PMU) are the sum of RAC horsepower units (PU) and the vehicle mass in units of 50 Kg (MU). Refined logic was developed by MUARC based on make, year, PMU, PU, MU and bodytype, and extended to cover 1989-90 models. Both logics were applied to the combined Victorian data to derive passenger car models for the model years 1982-90.

The NRMA had decoded the chassis number (obtained from the NSW vehicle register) to determine the models of light passenger vehicles which crashed in NSW. The decoding identified some light truck and other commercial models which were not considered further. In addition, because the Victorian data was limited to cars and station wagons, the four-wheel drive and passenger van models in the NSW data were analysed separately.

All but 8% of the NSW vehicles had a model identified; in these cases the make of the vehicle was used as the model in both States' data. Comparison between makes which contain more than one model should be made with care and may not be legitimate, because some manufacturers have a broad span of masses in their model range.

Expert advice was obtained regarding the models, years and bodytypes which needed to be kept separate, or could be aggregated, because of dissimilarity/similarity of crashworthiness aspects (this advice was used in the presentation of results). However some models have undergone substantial change during 1982-90 and their aggregate rating for all the year models released in this period needs to be interpreted with caution.

MEASURES TO RATE CRASHWORTHINESS

Crashworthiness ratings measure the risk of serious injury to the drivers of each specific model car when it is involved in a crash. This risk can be measured in two components:

- risk of injury for drivers involved in crashes ("**injury risk**"), and
- risk of serious injury for drivers who are injured ("**injury severity**").

Following the method used by Folksam Insurance (Gustafsson et al 1989), it is then possible to calculate an overall crashworthiness rating, defined as:

Combined Rate = Injury Severity x Injury Risk.

The combined rate defined in this way can be interpreted as measuring the risk of serious injury to drivers involved in a crash. Serious injury can be variously defined, but in this study, serious injury was taken as death, or injury requiring hospital admission.

Aldman et al (1984) recommended that *"when individual car models are studied the possible influence of the age of the driver, speed limit at the scene of the accident, belt usage rate, weight of the struck car, (and) impact direction ... must be taken into account"*. Major differences in crash patterns between models of cars have the potential to hide any effects of the vehicle design on injury risk or injury severity. It is necessary to take account of these differences if valid comparisons of the crashworthiness of cars are to be made.

The variables in the data files which described the crash patterns included speed zone, crash type, point of impact on the car, car mass, and restraint use. The driver age and sex are related to injury susceptibility. The first question was whether any of these variables had a significant relationship with the injury severity and injury risk measures selected for rating crashworthiness. The second question was whether the significant variable differed enough between makes/models for this to make a substantial difference to the rating scores. These questions were investigated separately for each measure (Cameron et al 1992) and the findings are summarized in the following sections.

Injury Severity of Injured Drivers

The data on injured drivers from Victoria and NSW was pooled to measure injury severity by model of car, ie. to provide the first component of the combined rate. In the pooled data, 5193 of the 22964 injured drivers were killed or hospitalised, representing an injury severity of 22.6 per 100 injured drivers. This was considered sufficiently similar to the separate injury severities from Victoria (24.5%) and NSW (20.3%) to justify combining the two States' data. The standard deviation of the pooled injury severity (0.27) was substantially lower than that for either State alone. Thus the pooled data has greater sensitivity and reliability than the separate data sets.

In both the Victorian and NSW data files on injured drivers, it was found that the driver sex and the speed zone at the crash location (in two categories: up to 75 km/h; 80 km/h and above) were both strongly related to injury severity and they both varied substantially across makes and models of crash involved cars. Other factors influencing injury severity were either associated with speed zone or, like driver age above 60, varied so little across models that their overall effect was relatively small compared with driver sex and speed zone.

The differences in driver sex and speed zone between models of cars were taken account by normalisation, a method used by HLDI (1991) following Armitage (1971). This was achieved by calculating the injury severity for drivers within each of the four categories of sex by speed zone, then combining the four figures using a constant mix of these categories for each model (the mix was in fact the average mix for all models combined). Thus every model was treated as if it had the same mix of male and female drivers and crashes in the high and low speed zones. This was essential to allow comparisons which related to vehicle differences rather than to injury susceptibility and other differences in the crash circumstances.

In the pooled data from the two States, 22626 (or 98.5%) of the injured drivers had known sex and speed zone. This data was the basis for calculating the normalised injury severity for each car model.

Injury Risk of Drivers Involved in Crashes

Because the Victorian data file did not include all uninjured drivers involved in crashes, it was not used to calculate injury risk for the main results. The file of 73399 drivers of 1982-90 model cars crashing in NSW during 1989-90 included 63302 who were not recorded as injured on the Police report. Some of their crashes may have been reported due to other persons being injured, but most were reported because a vehicle was towed away. This means that the injury rate is essentially an unbiased measure of the driver's injury risk in tow-away crashes. Thus the driver injury rate was used for the second component of the combined rate. The overall injury rate of the NSW drivers was 13.8 per 100 involved drivers with a standard deviation of 0.13.

The influence of crash patterns and driver characteristics on the comparisons of injury rates between models of cars was also investigated. Like injury severity, it was found that the driver sex and the speed zone were each strongly related to injury rate (and each varied substantially across makes and models of crash involved cars). Other factors had relatively small effects. Accordingly, the driver injury rate for each model car was normalised by driver sex and speed zone in a similar way as the driver injury severity described above.

Among the crash involved drivers from NSW, 70916 (or 96.6%) had known sex and speed zone. This data was the basis for calculating the normalised injury rate for each car model.

Relative Injury Risk in Two Car Crashes

As part of the study, there was a need for an independent assessment of driver injury risk derived from Victorian data alone, so that crashworthiness ratings from the two States' data could be calculated separately and compared (Cameron et al 1992). However, as noted above, this could not be done in the same way as for drivers involved in crashes in NSW, due to the incomplete coverage of uninjured drivers in the Victorian data.

The method developed by Folksam Insurance (Gustafsson et al 1989), for measuring injury risk from data in which essentially only injury crashes are recorded, was applied to the Victorian data. The method was derived by Folksam from Evan's (1986) double-pair comparison method. For two-car crashes, the method calculates the relative risk of injury to drivers of a specific model of car, relative to the injury risk of drivers of other model cars. The method is only applicable to two-car crashes, and this crash type covers about 60% of the drivers recorded in the Victorian data files.

In calculating relative injury risk, driver injury was defined as making a TAC claim. In the Victorian data on crashes prior to 1987, the claim status of drivers of only the 1982-86 model cars was known (and not drivers of earlier model cars colliding with them), so these crashes were ignored in the calculation. In the remaining data there were 8743 two-car crashes during 1987-90 in which at least one of the cars was a 1982-90 model and the TAC claim status of both drivers was known.

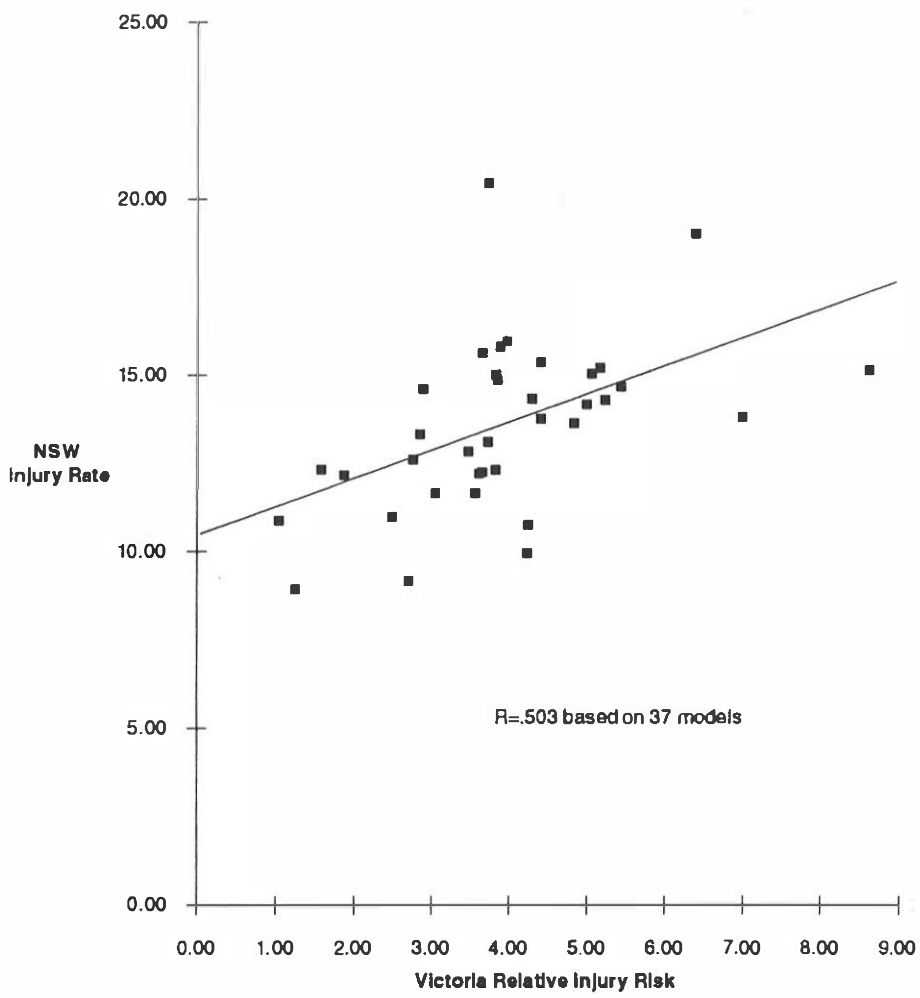
The relative injury risk was normalised for driver sex differences by calculating separate relative risks for the female and male drivers of each model, and then calculating the normalised figure by giving each sex the weighting observed on average for all models. There were too few two-car crashes in speed zones 80 km/h and above to justify normalisation by speed zone as well.

Victorian Relative Injury Risk compared with NSW Injury Rate

While the NSW driver injury rate may appear to be a simpler and more definitive method of estimating driver injury risk, in practice many jurisdictions record only injury crashes in their mass data and the relative injury risk method must be considered instead. For this reason it is important to know whether the relative injury risk is an adequate predictor of the injury rate.

FIGURE 1

NSW INJURY RATE v. VICTORIA RELATIVE INJURY RISK



The two measures of driver injury risk were compared for those car models where the coefficient of variation (standard deviation divided by the estimate) of each measure was less than 50% (Figure 1). There was a highly significant ($p < 0.01$) correlation between the the measures ($R = 0.503$).

In principle, the Victorian relative injury risk was not directly comparable with the NSW driver injury rate because the former pertained to two-car crashes only and the latter was normalised by speed zone as well as driver sex. Hence the relative injury risk was also compared with two alternative versions of the NSW driver injury rate, in each case limited to drivers involved in two-car crashes (73% of the total drivers involved), but using two different methods of normalisation. Each comparison displayed a highly significant correlation, with the following correlation coefficients:

- $R = 0.489$ when the NSW injury rate was normalised for driver sex only (ie. the closest match to the Victorian method),
- $R = 0.523$ when the NSW injury rate was normalised for driver sex and speed zone.

The significant correlation between each of the comparisons suggests that both general methods in fact measure the risk of injury to drivers involved in crashes. It was also concluded that, while the measures are correlated, the strength of the association between them is such that the relative injury risk method cannot be considered to be an adequate substitute for the injury rate (of drivers involved in tow-away crashes) in terms of measuring driver injury risk.

Combined Rate

The combined rate for each model was calculated by multiplying the driver injury severity (based on Victorian and NSW data) by the driver injury rate (based on NSW data). Thus the combined rate was normalised by driver sex and speed zone, because each of its components was separately normalised. The two components, respectively, measure:

- the risk of death or hospitalisation for drivers who were injured in a crash, and
- the risk of injury for drivers involved in tow-away crashes.

The combined rate can thus be interpreted as measuring the risk of death or hospitalisation for drivers involved in tow-away crashes. The overall combined rate was 3.14 per 100 involved drivers with a standard deviation of 0.05.

CRASHWORTHINESS RATINGS BY MODEL OF VEHICLE

Crashworthiness ratings based on the combined rate defined above were calculated for each model of passenger car and station wagon, where there was sufficient data to calculate each normalised component of the combined rate. These calculations made use of data from Victoria and NSW crashes.

Separate ratings were calculated for four-wheel drive vehicles and passenger vans because the models of these types of vehicles were available only in the NSW data. The raw figures were not directly comparable with those for cars and station wagons, because the overall combined rate (for all types of vehicle) based on NSW data alone was only 2.80 per 100 involved drivers. To facilitate a direct comparison, the combined rates for the four-wheel drive and passenger van models were rescaled (by the ratio 3.14/2.80).

Rating Scores

The crashworthiness rating score for each model of car, station wagon, four-wheel drive vehicle and passenger van is presented in Table 2 (in bold type), sorted in ascending order within market group. These groups reflect the general market categories within which consumers typically make a decision about which model to purchase in Australia. The rating scores for the makes which were not separated into models are presented in Table 3.

The rating score for each pair of models which could be aggregated (because the models are believed to be essentially the same so far as crashworthiness aspects are concerned) is their aggregate rating, ie. the same value is assigned to each of the models (in no case was there a statistically significant difference between their individual rating scores).

The standard deviation is a measure of the reliability of the rating score in estimating the crashworthiness of a specific model car. The standard deviation is a function of the number of involved and injured drivers in the data files. The true risk of driver death or hospitalisation in a crash could be expected to be within two standard deviations of the rating score with approximately 95% confidence. Thus each rating score has error limits spanning two standard deviations on each side of the score, also shown in Tables 2 and 3.

It was decided that the rating score should not be reported if it does not provide a reliable estimate of the crashworthiness of the specific model car (or aggregate of two models). The results in Tables 2 and 3 exclude those makes and models where:

- there were insufficient involved or injured drivers to calculate both of the components of the rating score (ie. combined rate) for the specific model,
- the standard deviation of the rating score exceeded 1.5, or
- the coefficient of variation of the rating score exceeded 70% (this criterion was also necessary because small standard deviations tended to occur for the lower rating scores, but the standard deviations were relatively high in proportionate terms).

The error limits can be used to judge whether the rating score is sufficiently different from the all make/model average (3.14 per 100 involved drivers) for this to be unlikely to be due to chance. An upper limit below the average is indicative of superior crashworthiness, whereas a lower limit above the average suggest inferior crashworthiness. This could occur by chance only about 5% of the time. Of the 62 makes and models for which the rating score could be calculated reliably, eight displayed an upper limit below the average and one displayed a lower limit greater than the average.

DISCUSSION

The rating scores given in Tables 2 and 3 measure the risk of death or hospitalisation of drivers of specific makes and models of vehicles involved in crashes. The question is whether the figures represent the crashworthiness of the vehicle alone, or whether they also

TABLE 2: CRASHWORTHINESS RATINGS OF 1982-90 MODEL VEHICLES INVOLVED IN CRASHES

MAKE	MODEL OF CAR	YEARS OF MANUFACTURE INVOLVED IN CRASHES	RISK OF DEATH OR HOSPITALISATION FOR DRIVERS INVOLVED IN CRASHES			ERROR LIMITS OF THE RATING (2 Std. Devs.)	
			Rating Per 100 Drivers	Standard Deviation	Coeff. of Variation	Lower Limit	Upper Limit
All Make/Model Average			**3.14**	0.05	1.51%		
LARGE CARS							
Ford	FALCON E SEDAN	1988-90	**1.85**	0.45	24.16%	0.96	2.74
Holden Toyota	COMMODORE VN LEXCEN	1988-90 1988-90	**2.39**	0.41	17.18%	1.57	3.21
Mitsubishi	MAGNA	1984-90	**2.40**	0.25	10.26%	1.90	2.89
Nissan	SKYLINE	1982-90	**2.62**	0.48	18.35%	1.66	3.58
Ford	FALCON X SEDAN	1982-88	**2.65**	0.16	5.85%	2.34	2.96
Ford	FALCON X WAGON	1982-88	**2.75**	0.31	11.40%	2.12	3.37
Ford	FALCON E WAGON	1988-90	**2.75**	0.93	33.74%	0.89	4.60
Holden	COMMODORE VH-VL	1982-88	**2.99**	0.16	5.40%	2.67	3.32
Large Car Average			**2.69**				
MEDIUM CARS							
Holden Toyota	APOLLO CAMRY (89-90)	1989-90 1989-90	**2.55**	0.66	25.74%	1.24	3.87
Nissan	PINTARA	1986-90	**2.71**	0.56	20.83%	1.58	3.83
Toyota	CAMRY (83-88)	1983-88	**2.97**	0.43	14.48%	2.11	3.83
Toyota	CORONA	1982-87	**3.16**	0.30	9.51%	2.56	3.77
Mitsubishi	SIGMA/SCORPION	1982-87	**3.25**	0.28	8.47%	2.70	3.80
Nissan	BLUEBIRD	1982-86	**3.28**	0.31	9.45%	2.66	3.90
Mazda Ford	MAZDA 626 TELSTAR	1982-90 1983-90	**3.37**	0.25	7.52%	2.86	3.87
Holden	CAMIRA	1982-89	**3.53**	0.25	7.15%	3.03	4.04
Mitsubishi	NIMBUS	1984-90	**3.73**	1.34	36.04%	1.04	6.42
Nissan	GAZELLE	1983-86	**4.11**	1.35	32.84%	1.41	6.81
Medium Car Average			**3.27**				
SMALL CARS							
Mitsubishi	LANCER	1988-90	**2.18**	0.91	41.92%	0.35	4.00
Toyota Holden	COROLLA NOVA	1982-90 1989-90	**3.38**	0.23	6.81%	2.92	3.84
Mazda	MAZDA 323	1982-90	**3.39**	0.46	13.66%	2.46	4.32
Ford	METEOR/LASER	1982-90	**3.46**	0.20	5.67%	3.07	3.85
Holden Nissan	ASTRA VECTOR/PULSAR	1984-89 1982-90	**3.52**	0.28	8.06%	2.95	4.09
Mitsubishi	COLT	1982-90	**3.53**	0.42	11.81%	2.70	4.37
Mitsubishi	CORDIA	1982-88	**4.05**	0.89	22.06%	2.26	5.84
Honda	CIVIC	1982-90	**4.08**	0.67	16.40%	2.74	5.42
Holden	GEMINI	1982-88	**4.21**	0.41	9.77%	3.38	5.03
Hyundai	EXCEL	1986-90	**4.27**	0.90	21.05%	2.47	6.06
Holden Suzuki	BARINA SWIFT	1984-90 1984-90	**4.52**	0.73	16.23%	3.05	5.98
Daihatsu	CHARADE	1982-90	**4.69**	0.82	17.42%	3.06	6.32
Small Car Average			**3.57**				
SPORTS CARS							
Toyota	CELICA	1982-90	**3.03**	0.66	21.76%	1.71	4.35
Mazda	RX7	1982-90	**3.72**	1.01	27.10%	1.70	5.74
Sports Car Average			**3.24**				

TABLE 2(cont): CRASHWORTHINESS RATINGS OF 1982-90 MODEL VEHICLES INVOLVED IN CRASHES

MAKE	MODEL OF CAR	YEARS OF MANUFACTURE INVOLVED IN CRASHES	RISK OF DEATH OR HOSPITALISATION FOR DRIVERS INVOLVED IN CRASHES			ERROR LIMITS OF THE RATING (2 Std. Devs.)	
			Rating Per 100 Drivers	Standard Deviation	Coeff. of Variation	Lower Limit	Upper Limit
All Make/Model Average			**3.14**	0.05	1.51%		
LUXURY CARS							
Volvo	VOLVO 700 SERIES	1984-88	**1.31**	0.76	58.19%	0.00	2.84
Holden	STATESMAN	1982-86	**1.51**	0.52	34.39%	0.47	2.54
Ford	FAIRLANE N & LTD D	1988-90	**2.05**	0.85	41.20%	0.36	3.74
Honda	ACCORD	1982-90	**2.58**	0.68	26.33%	1.22	3.95
Honda	PRELUDE	1982-90	**2.63**	0.77	29.41%	1.08	4.17
Toyota	CRESSIDA/CROWN	1982-90	**2.70**	0.59	21.73%	1.53	3.88
Volvo	VOLVO 200 SERIES	1982-90	**2.88**	0.75	26.07%	1.38	4.38
Ford	FAIRLANE Z & LTD F	1982-87	**3.13**	0.50	15.89%	2.14	4.13
Mazda	MAZDA 929	1982-90	**3.56**	0.72	20.25%	2.12	5.00
Luxury Car Average			**2.49**				
4 WHEEL DRIVE VEHICLES							
Nissan	PATROL/PATHFINDER	1982-90	**1.98**	0.75	37.97%	0.48	3.48
Holden	JACKAROO	1983-90	**2.08**	0.72	34.88%	0.63	3.53
Daihatsu	ROCKY	1984-90	**2.15**	1.46	68.06%	0.00	5.07
Toyota	4RUNNER/LAND CRUISER	1982-90	**2.70**	0.60	22.31%	1.50	3.91
Mitsubishi	PAJERO	1983-90	**3.03**	1.24	41.02%	0.54	5.52
Nissan	NAVARA	1984-90	**4.17**	1.38	33.13%	1.41	6.94
Suzuki	SIERRA	1982-90	**4.85**	1.37	28.24%	2.11	7.58
4 Wheel Drive Average			**2.63**				
PASSENGER VANS							
Toyota	HILUX/HI & LITEACE	1982-90	**3.42**	0.54	15.79%	2.34	4.49
Ford	COURIER	1982-89	**3.90**	1.04	26.69%	1.82	5.99
Mitsubishi	MITSUBISHI VANS	1982-90	**3.96**	0.80	20.27%	2.36	5.57
Toyota	TARAGO	1983-85	**4.10**	1.40	34.06%	1.31	6.89
Passenger Van Average			**3.67**				

TABLE 3: CRASHWORTHINESS RATINGS OF 1982-90 MODEL CARS (BY MAKE) INVOLVED IN CRASHES

MAKE	MODEL OF CAR	YEARS OF MANUFACTURE INVOLVED IN CRASHES	RISK OF DEATH OR HOSPITALISATION FOR DRIVERS INVOLVED IN CRASHES			ERROR LIMITS OF THE RATING (2 Std. Devs.)	
			Rating Per 100 Drivers	Standard Deviation	Coeff. of Variation	Lower Limit	Upper Limit
CARS BY MAKE ONLY							
SAAB		1982-90	**1.77**	0.68	38.39%	0.41	3.12
Rover		1982-89	**1.78**	0.73	40.82%	0.33	3.24
B M W		1982-90	**1.93**	0.49	25.60%	0.94	2.92
Mercedes		1982-90	**2.07**	0.52	24.97%	1.04	3.10
Renault		1982-89	**2.39**	1.07	44.69%	0.25	4.53
Fiat		1982-89	**2.70**	1.30	48.15%	0.10	5.30
Alfa Romeo		1982-90	**2.80**	0.74	26.45%	1.32	4.28
Peugeot		1982-90	**2.94**	1.00	34.06%	0.94	4.94
Subaru		1982-90	**3.40**	0.41	12.09%	2.57	4.22
Range Rover		1982-89	**3.45**	1.25	36.36%	0.94	5.96

Note: The results in this table, which represent several different models of different mass, are not directly comparable with those in Table 2, for a single make/model reflect other differences between vehicles related to the crashes in which they were involved or to physiological and other characteristics of the driver.

The analysis has recognised that a number of factors available in the data could affect the rating scores. The most important of these factors were the driver sex and speed zone, and the variations in these factors between makes and models were taken into account. Other factors which were strongly associated with the high speed zones (eg. single-vehicle crashes, fixed object collisions, and rollovers) were also taken into account with speed zone due to the strong association. Driver age, which could be expected to affect injury susceptibility, did not appear to vary sufficiently between models of cars to have a substantial effect on the rating scores.

However the analysis was not able to take into account other potentially important factors which were not measured in the data, eg. the crash speed of the vehicle (to the extent that variations in this factor were not reflected in the speed zone at the crash location). The absence of such information from Police accident reports and injury compensation claim records is a limitation of this type of data. However, the large number of cases available in these files provide the opportunity to measure the risks of serious injury to crash involved drivers reliably.

The crashworthiness of vehicles sold and crashing in Victoria and NSW would not be expected to differ between the States. The technical report demonstrated a statistically significant correlation between the rating scores derived for the two States independently (even though they used different methods of analysis for a component of the figures, ie. driver injury risk) (Cameron et al 1992). As the vehicles were the only common factor between the two States, the presence of a correlation suggests that both sets of rating scores are measuring the same thing, ie. the crashworthiness of the vehicles alone.

It follows that the rating scores based on both States' data combined are also likely to measure crashworthiness alone, and presumably more reliably. The reliability of the current rating scores is indicated by the standard deviations and error limits given in Tables 2 and 3.

Comparison of the rating scores can be made for each pair of models, within the limits of their individual levels of reliability. The most reliable comparisons are for those pairs of models where the error limits do not overlap. The limited reliability of the relative comparisons is obvious when the general width of the error limits is examined.

CONCLUSIONS

1. The rating scores in Tables 2 and 3 measure the crashworthiness of the makes and models of vehicles, free from the effects of driver sex and speed zone differences between models. The analysis suggests that the different rating scores were predominantly due to vehicle factors alone.

2. Each rating score is reliable in indicating the crashworthiness of the vehicle specified to the extent indicated by the error limits of the score.

3. The rating scores can be used to make reliable comparisons of the crashworthiness of pairs of models when the error limits do not overlap.

4. The Folksam "relative injury risk" of drivers involved in two-car crashes, while significantly correlated with the driver injury rate in tow-away crashes, is not an adequate substitute for this rate in order to measure driver injury risk.

ASSUMPTIONS AND QUALIFICATIONS

The results and conclusions presented in this paper are based on a number of assumptions and warrant a number of qualifications which should be noted.

Assumptions

. TAC claims records and NSW Police accident reports accurately recorded driver injury, hospitalisation and death.

. There was no bias in the merging of TAC claims and Victorian Police accident reports related to crash exposure factors and model of car.

. Crashed vehicle registration numbers were recorded accurately on Police accident reports and that they correctly identified the crashed vehicles in the Victorian and NSW vehicle registers.

. The adjustment for driver sex and speed zone was sufficient to remove the influences of the main factors available in the data which affected crash severity and injury susceptibility. (Other factors examined had smaller effects on injury severity or injury risk, and/or varied by relatively small amounts between models.)

Qualifications

. Only driver crash involvements and injuries have been considered. Passengers occupying the same model cars may have had different injury outcomes which may have suggested a different assessment of the crashworthiness of the cars in terms of protecting all their occupants from injury.

. The makes of cars which could not be disaggregated into models may include a range of models with a broad span of masses or other factors affecting crashworthiness. The rating score calculated for these makes should not be interpreted as applying to each model of these manufacturers.

. Some models with the same name through the 1982-90 years of manufacture varied substantially in their construction and mass. The rating score calculated for these models may give a misleading impression and should be interpreted with caution.

. Other factors not collected in the data (eg. crash speed) may differ between the makes and models and may affect the results.

REFERENCES

ALDMAN, B., GUSTAFSSON, H., NYGREN, A., TINGVALL, C., and WERSALL, J. (1984), "Injuries to Car Occupants - Some Aspects of the Interior Safety of Cars". Folksam, Stockholm.

ARMITAGE, P. (1971), Statistical Methods in Medical Research. Wiley, New York.

CAMERON, M.H. (1991), "Vehicle Crashworthiness Ratings from Mass Crash Data". Proceedings of Seminar *Road Trauma: The Medical-Engineering Link*, Association for the Advancement of Automotive Medicine, in cooperation with the Royal Australasian College of Surgeons, Melbourne, July 1991.

CAMERON, M.H., MACH, T., and NEIGER, D. (1992), "Vehicle Crashworthiness Ratings: Victoria 1983-90 and NSW 1989-90 Crashes - Technical Report". Report No. 25, Monash University Accident Research Centre.

CAMPBELL, B.J., and REINFURT, D.W. (1973), "Relationship between Driver Crash Injury and Passenger Car Weight". Highway Safety Research Center, University of North Carolina, Chapel Hill.

DOWDELL, B. (1990a), "Consumer Driven Countermeasures". Proceedings, 1990 Road Safety Researchers Conference, Queensland.

DOWDELL, B. (1990b), "Future Directions in Occupant Protection". Proceedings, 1990 Road Safety Researchers Conference, Queensland.

DEPARTMENT OF TRANSPORT (DOT) (1991), "Car and Driver: Injury Accident and Casualty Rates, Great Britain: 1989". Transport Statistics Report, UK DOT. HMSO, London.

EVANS, L. (1986), "Double Pair Comparison - A New Method To Determine How Occupant Characteristics Affect Fatality Risk in Traffic Crashes". Accident Analysis and Prevention, Vol. 18, No. 3.

FOLKSAM (undated), "Safe and Dangerous Cars 1989-90". Division for Research and Development, Folksam, Stockholm.

GILLIS, J. (1991), "The Car Book (1991 Edition)". Harper Collins, New York.

GREEN, P. (1990), "Victorian Road Accident Database: Frequency Tables for Accident Data Fields: 1988". Accident Studies Section, VIC ROADS.

GUSTAFSSON, H., HAGG, A., KRAFFT, M., KULLGREN, A., MALMSTEDT, B., NYGREN, A., and TINGVALL, C. (1989), "Folksam Car Model Safety Rating 1989-90". Folksam, Stockholm.

HIGHWAY LOSS DATA INSTITUTE (HLDI) (1991), "Injury and Collision Loss Experience by Make and Model". HLDI, Arlington, Virginia.

INSURANCE INSTITUTE FOR HIGHWAY SAFETY (IIHS) (1991), Status Report (Special Issue: Occupant Death Rates: 1984-88 Model Cars). Vol. 26, No. 4, 13 April. IIHS, Washington, DC.

JOHNSTON, I.R. (1984), "Human Factors in Road Accidents". Papers, Symposium on "The Road Toll", Institution of Engineers Australia. Queensland Division Technical Papers, Vol. 25, No. 14.

SOCIAL DEVELOPMENT COMMITTEE (1990), "Inquiry into Vehicle Occupant Protection". Parliament of Victoria.

VEHICLE SAFETY CONSULTANTS (1989), "The Secondary Safety Rating System for Cars". Developed for the Consumers' Association, UK.