RATING THE AGGRESSIVITY OF AUSTRALIAN PASSENGER VEHICLES TOWARDS OTHER VEHICLE OCCUPANTS AND UNPROTECTED ROAD USERS

Max Cameron, Stuart Newstead and Chau My Le
Monash University Accident Research Centre, Victoria, Australia

ABSTRACT

Since 1990, Monash University Accident Research Centre has conducted a series of studies to provide consumer advice on the crashworthiness of individual makes and models of Australian passenger cars. Crashworthiness has been defined as the relative safety of a vehicle in preventing severe injury to its driver when involved in a crash. A concept complementary to crashworthiness is vehicle aggressivity. Aggressivity can be defined as the risk of injury which a vehicle poses to occupants of other vehicles which it impacts, and to unprotected road users such as pedestrians, bicyclists and motorcyclists.

This paper describes the development of aggressivity ratings for Australian passenger vehicles. Two measures have been considered:
1. Aggressivity to occupants of other cars : This type of aggressivity rating is based on two-car crashes between passenger vehicles and measures the injury risk each make/model in the collisions poses to the drivers of the other vehicles.
2. Aggressivity to unprotected road users : The aggressivity ratings reflect the threat of severe injury to pedestrians, bicyclists and motorcyclists by the make/model of vehicle colliding with them.

The analysis was based on nearly 102,000 drivers involved in tow-away crashes with the makes/models which were the focus of the study, and on nearly 22,000 injured pedestrians, bicyclists and motorcyclists. The aggressivity ratings are presented and discussed, along with their relationship to crashworthiness ratings for the same makes and models of vehicles. The results suggest that crashworthiness and aggressivity are two different aspects of a vehicle's safety performance, with good performance on one dimension not necessarily being associated with good performance on the other.

Paper presented to the 1998 IRCOBI Conference on the Biomechanics of Impacts, September 16-18, 1998 - Göteborg, Sweden

SINCE 1990, Monash University Accident Research Centre (MUARC) has conducted a series of studies to provide consumer advice on the crashworthiness of individual makes and models of Australian passenger cars. Crashworthiness was defined as the relative safety of vehicles in preventing severe injury to their occupants in crashes. Ratings of crashworthiness, measured by the rate of serious driver injury in tow-away crashes, were produced for individual models (Cameron et al 1992; Cameron et al 1995; Cameron, Newstead and Skalova 1996).

This paper extends MUARC's previous work in this area to add measures of the "aggressivity" of individual car models when they crash. Aggressivity ratings measure the risk of injury which a vehicle poses to occupants of other vehicles which it impacts, and to other, unprotected road users such as pedestrians, bicyclists and motorcyclists. The addition of aggressivity ratings represents further consumer advice which purchasers of cars could take into account when choosing a specific model.

DEVELOPMENTS IN EUROPE

Broughton (1994, 1996) has defined an aggressivity index which is calculated for each car model (eg. M) from mass data on two-car crashes in which at least one driver is injured. The index was based on the same type of data used by Folksam Insurance, Sweden (Gustafsson et al 1989) and the U.K. Department of Transport (1995) to calculate their respective crashworthiness indices (Table 1). In both Sweden and the U.K., non-injury crashes are not (fully) reported, so the number of two-car crashes in which neither driver is injured (ie. n_4) is not known and hence cannot be used in either a crashworthiness or aggressivity index.

Table 1: Number of two-car crashes between specific make/model (M) and other makes/models (O)

Drivers of other makes/models O	Drivers of make/model M	
	INJURED	NOT INJURED
INJURED	n_2	n_3
NOT INJURED	n_1	n_4

Broughton's aggressivity index is:

$$A = (n_2 + n_3) / (n_1 + n_2 + n_3).$$

Broughton has also pointed out that the U.K. DoT crashworthiness index,

$$D = (n_1 + n_2) / (n_1 + n_2 + n_3),$$

and the Folksam crashworthiness index,

$$R = (n_1 + n_2) / (n_2 + n_3),$$

are related through the relationship D / A = R.

Broughton shows that both D and R are influenced by the aggressivity of the specific model (ie. independent of their occupant protection capabilities, the models which inflict more injuries on "other" drivers will have lower crashworthiness indices), but also that D comes closer than R to the ideal of being independent of the casualties in the "other" car. Thus it appears that the Folksam index, R, is particularly likely to be a measure of not only the crashworthiness of a car model, but also its aggressiveness (the above relationship suggests that a more aggressive model will appear to be more crashworthy, if R is used as the measure of crashworthiness).

Turning to Broughton's aggressivity index, A, and the DoT crashworthiness index, D, both Broughton and DoT have reported a strong inverse relationship between them when each is calculated for a range of car models included in the U.K. ratings. Relatively few models departed substantially from the curvilinear relationship fitted to the data by Broughton. This suggests that either U.K. cars are truly characterised by an inverse relationship between aggressivity and crashworthiness, or that the apparent relationship is at least in part an artefact of the constraints on the data (ie. crashes with at least one injured driver) used to produce the indices for each model. It is hoped to avoid these constraints by the use of Australian data on crashes based on the tow-away criterion for collection.

More recently, an international working group on criteria for the safety assessment of cars has had searching discussions at two meetings in Germany during 1995 and 1996 (Langwieder and Fildes, 1997). While not specifically addressing the question of aggressivity ratings to date, they resolved at their second meeting that "rating criteria for ... compatibility and partner protection should be subject to further consideration in future".

DEVELOPMENTS IN THE UNITED STATES

Hollowell and Gabler (1996) describe an NHTSA research program aimed at measuring vehicle aggressivity and compatibility and then linking these to vehicle design characteristics.

They calculated an "aggressivity metric", defined as

$$\text{Aggressivity Metric} = \frac{\text{Deaths in Other Vehicle}}{\text{(Total Registrations in Subject Vehicle) / 1,000,000}}$$

For each make and model of cars, light trucks and vans under 10,000 pounds, the metric was calculated from data on two-car collisions involving a fatality, recorded in the Fatal Accident Reporting System (FARS) database for 1991-93. This metric showed that the most aggressive vehicles were light trucks (pickups and sports utility vehicles) and vans and that, among cars, the heavier models were the most aggressive. However, the detailed results also showed that weight is not always the over-riding contributor to aggressivity, as some heavy cars had relatively low scores on the metric.

Hollowell and Gabler recognised that a poor aggressivity rating may reflect characteristics of the driver and how the vehicle is driven (eg. speed), as well as any structural or weight factor. At the very least, their metric is influenced by the crash rate per million registrations of each model, and variations in this rate should not be included in an aggressivity index aiming to measure the threat to other road users involved in a crash with the subject model. They also calculated two other metrics to at least partially overcome these problems:

- the other vehicle fatalities divided by the subject vehicle fatalities, and
- the other vehicle fatalities divided by the subject vehicle fatal accidents.

These two metrics reduced the initial aggressivity ranking of a model which presumably had a relatively high crash rate. The first of these alternative metrics is similar to Broughton's aggressivity index, where "injury" is redefined as death.

When describing future work, Hollowell and Gabler alluded to the lack of an accepted measure of aggressivity, even though they had presented three different metrics in their paper. They listed a number of proposed variations which will be evaluated in future, namely:

1. Normalising by number of accidents instead of number of registrations
2. Normalising for the effect of restraint usage in either vehicle
3. Normalising for accident severity
4. Examining the metric in prescribed accident modes, eg. frontal-side impacts or frontal-frontal impacts
5. Examining rollovers and full ejections from either vehicle
6. Limiting the other vehicle fatality count to cases where the subject vehicle was the striking vehicle.

AGGRESSIVITY RATINGS FOR AUSTRALIAN PASSENGER VEHICLES

This paper describes an investigation of the feasibility and methods of providing aggressivity ratings for Australian passenger vehicles in terms of the threat which each subject model represents to:

1. Occupants of other cars colliding with the subject model cars, and
2. Pedestrians, bicyclists and motorcyclists impacted by the subject model cars.

The aggressivity ratings were based on one of the data sets used to produce crashworthiness ratings (Newstead, Cameron and Le 1997), namely Police reports of crashes in New South Wales (NSW) resulting in death or injury or a vehicle being towed away.

Crashes involving pedestrians, bicyclists and motorcyclists are seldom reported to the Police in NSW unless someone is killed or injured (usually the unprotected road user). This means that an estimate of the risk of injury was not calculable for the unprotected road users for inclusion in the second type of aggressivity rating (a measure of injury severity was). This problem did not occur for drivers of other cars, for whom the available data allowed estimates of both the risk of injury and of their injury severity.

AGGRESSIVITY TOWARDS OCCUPANTS OF OTHER CARS - As in Europe and the United States, this type of aggressivity rating has been based on two-car crashes between light vehicles (ie. heavy vehicle collisions were excluded). The subject vehicles were the passenger cars, station wagons, four-wheel drive vehicles, passenger vans and light commercial vehicles manufactured during 1982-95 whose makes and models have been identified in the NSW crash data.

The NSW data on two-car crashes involving each model of the subject vehicle has been extracted in the same form as Table 1. In this case, the number of crashes in which neither driver was injured (ie. n_4) was available, at least so far as tow-away crashes are concerned. The measure of the risk of injury of the other drivers colliding with the subject model, unadjusted for any other factors, was:

$$\text{Injury risk of other drivers} = RO = (n_2 + n_3) / (n_1 + n_2 + n_3 + n_4).$$

The injury severity of other drivers could be measured in a number of ways from the information on injury recorded on NSW Police reports (viz. killed; admitted to hospital; or injury requiring medical treatment). The measure of injury severity, similar to that used in the crashworthiness ratings project, was:

Injury severity of other drivers = SO = proportion of injured drivers who were killed or admitted to hospital.

The aggressivity measure for each subject car model, assuming RO and SO are independent, was then calculated as:

$$\text{Aggressivity to other car drivers} = AO = RO \times SO.$$

This measured the risk of a driver of other cars being killed or admitted to hospital when involved in collisions with the subject model cars.

Before this aggressivity measure was calculated, consideration was given to taking into account the differences between the crash circumstances of the subject car models which may result in a distorted view of its aggressivity only partly related to the characteristics of the subject cars. Factors available in the data to consider such differences included:

- speed limit at the crash location
- subject driver age (younger drivers may be driving at relatively fast speeds not fully represented by the speed limit)
- subject driver sex (male drivers may be driving at relatively fast speeds)
- other car driver age (older drivers are more susceptible to injury)
- other car driver sex (female drivers are more susceptible to injury, but males appear to be associated with relatively high injury severities).

AGGRESSIVITY TOWARDS PEDESTRIANS, BICYCLISTS AND MOTORCYCLISTS - The aggressivity ratings reflecting the threat to pedestrians, bicyclists and motorcyclists have been based on NSW data on collisions between these road user types and the subject model vehicles with identified makes and models. The aggressivity measure was based on injured pedestrians, bicyclists and motorcyclists and reflects the injury severity of their outcome. The measure of the aggressivity of the subject models towards unprotected road users was:

Aggressivity to unprotected road users = AU
= proportion of unprotected road users injured in collisions with subject car models who were killed or admitted to hospital.

As with the measure of aggressivity to drivers of other cars, consideration was given to taking into account any major differences in the crash circumstances related to the following factors which may distort the results:

- speed limit at the crash location
- subject driver age
- subject driver sex
- unprotected road user age
- unprotected road user sex
- type of unprotected road user.

DATA

The NSW crash data available for estimation of vehicle aggressivity ratings was the same as that used by Newstead, Cameron and Le (1997) to produce crashworthiness ratings, namely Police reports of crashes during 1987-95 resulting in death or injury or a vehicle being towed away. They have described the method of assembly of this data including the means by which vehicle models were identified. Subsets of these data were taken in order to estimate the two aggressivity measures. The methods of selecting appropriate cases for each purpose are described below.

Data from New South Wales used to estimate the crashworthiness ratings covered 350,740 drivers of 1982-95 model vehicles involved in crashes resulting in at least one of the vehicles being towed, over the period 1987-95. Of these 350,740 vehicles, 250,762 were coded as being involved in crashes with one other vehicle (ie. the crash involved a total of two vehicles). In order to compare occupant injury levels between the two vehicles involved in the crash, it was necessary to match the crash and occupant injury information for the each of the two vehicles involved in the crash.

The data used for calculation of the crashworthiness ratings covered only vehicles manufactured from 1982 to 1995. Consequently, when matching the data to determine pairs of vehicles involved in a crash, it was only feasible to identify both the vehicles in the crash when both vehicles were manufactured from 1982 to 1995. Matching of the data identified 101,916 vehicles manufactured between 1982 and 1995 which had been involved in a crash with one other vehicle also manufactured in this time frame. Of the drivers of these vehicles, 12,311 were injured. These records were used for calculation of vehicle aggressivity ratings toward drivers of other vehicles.

For calculation of vehicle aggressivity ratings towards unprotected road users, the data from NSW was interrogated to identify single vehicles crashing with one pedestrian, bicyclist or motorcyclist. 21,899 crashes of this type were identified involving vehicles manufactured over the years 1982 to 1995. All the unprotected road users involved in these crashes were injured to some degree.

METHODS

AGGRESSIVITY TOWARDS OCCUPANTS OF OTHER CARS - As described above, the measure of aggressivity to drivers of other cars was:

$$AO = RO \times SO.$$

Each of the two components of the aggressivity rating, RO and SO, were estimated by logistic regression modelling techniques (Hosmer & Lemeshow, 1989). Such techniques are able to simultaneously adjust for the effect of a number of factors, discussed below, on the injury risk and injury severity probabilities.

Cameron et al (1998) also investigated an adjustment of the measure of aggressivity towards drivers of other cars which took into account the injury outcome of the drivers of the subject model cars, hence providing an indication of the crash severity. The logistic regression techniques employed allowed adjustment for the injury risk or injury severity of the driver of the subject vehicle by including this as a covariate in each of the logistic models for RO and SO, respectively. The subject driver injury outcome was a statistically significant predictor of the injury outcome of the driver of the other car, for each component RO and SO. However the inclusion of the subject driver injury outcome as a covariate made little difference to the overall aggressivity rating, AO, compared with that obtained when it was omitted. The results also suggest that the other factors included as covariates (see below) provide an adequate substitute for a direct measure of crash severity.

AGGRESSIVITY TOWARDS UNPROTECTED ROAD USERS - As described above, all unprotected road users were injured in the reported crashes, hence the concept of injury risk was redundant when considering aggressivity towards these road user types. The aggressivity measure for unprotected road users was equivalent to the injury severity component of the aggressivity measure for other drivers described above. That is:

$$\text{Aggressivity to unprotected road users} = AU.$$

Logistic regression modelling techniques were used to obtain estimates of AU adjusting for the effect of other factors, discussed below, on the aggressivity rating.

LOGISTIC REGRESSION ANALYSIS was applied to each of RO, SO and AU in turn to estimate the contribution of the subject model vehicle to variations in these probabilities. The methods of analysis, and calculation of the confidence limits for the estimates, were identical to those used for the crashworthiness ratings and described by Newstead et al (1997). As well as the subject vehicle model, other influential factors were included in the analysis to take their effect into account.

Before the final analysis could be undertaken, it was necessary to develop logistic models of each component (RO, SO and AU) to identify possible factors, other than vehicle design, that might have influenced the injury outcome of the other driver or unprotected road user. This was initially done without considering the type of car (make/model or market group) in the logistic regression model as the aim was to determine which other factors were most likely to have an influence across a broad spectrum of crashes.

Aggressivity Towards Occupants of Other Cars - Logistic models were obtained separately for RO and SO because it was likely that the various factors would have different levels and directions of influence on these two component probabilities of the aggressivity measure. The factors considered in the models for both injury risk and injury severity were:

- speed limit at the crash location (<80km/h, >= 80 km/h)
- age of driver of subject car (<=25 years, 26-59 years, >=60 years)
- sex of driver of subject car
- other car driver age (<=25 years, 26-59 years, >=60 years)
- other car driver sex.

Aggressivity Towards Unprotected Road Users - The influential factors considered in the logistic regression model for AU were :

- speed limit at the crash location
- age of driver of subject car (<=25 years, 26-59 years, >=60 years)
- sex of driver of subject car
- unprotected road user age (<=25 years, 26-59 years, >=60 years)
- unprotected road user sex
- type of unprotected road user (bicyclist, motorcyclist, pedestrian).

For all analyses, a stepwise procedure was used to identify which factors and their interactions made a significant contribution to the probabilities. All possible first and higher order interactions were considered. A hierarchal structure was imposed so that if an interaction between two variables was included in the model then the corresponding main effects would also be included. The resultant logistic regression models were referred to as the "covariate" models or equations.

Assessing Differences in Aggressivity Between Specific Car Models - Aggressivity injury risk, where relevant, and injury severity for individual vehicle models were estimated after adding a variable representing the subject car model to the respective logistic "covariate" models. The car model variable was added to the logistic equation and individual car model coefficients were computed to represent deviations of that car from the average.

It was important to ensure that the logistic model adequately described the data and did not yield individual car model coefficients that were imprecise or unstable. In a similar manner to the exclusion of models for calculation of crashworthiness ratings (Newstead et al 1997), car models were excluded for the calculation of aggressivity towards other vehicle drivers if :

i) there were less than 100 vehicles with which they had crashed, or
ii) there were less than 40 injured drivers in the other vehicles;
or models were excluded for calculation of aggressivity towards unprotected road users if there were less than 30 injured persons with which they had crashed.

Assessing Differences in Aggressivity Between Broad Market Groups - A similar approach to that for individual car models was used to assess car market group aggressivity averages. A variable representing the different market groups (large, medium, small, luxury, sports, 4-wheel drive, passenger vans, and commercial vehicles with GVM $\leq$ 3000 Kg) was added to each of the "covariate" models. Deviations of each market group, from the average, were assessed.

Combining the Injury Risk and Injury Severity Components - For aggressivity towards drivers of other vehicles, the final ratings were given by multiplying the estimates, RO and SO, for each individual subject car model (or market group). It was assumed that the probabilities estimated by these two components are independent. The influence of modern trends in barrier crash testing and other aspects of vehicle design on this assumption are unknown.

Because each of the two estimated aggressivity components had been adjusted for the effect of other factors by logistic regression prior to their combination, the resultant aggressivity rating was also adjusted for the influence of these factors. Since the aggressivity measure for unprotected road users was estimated as a single component, no combination of components was necessary.

RESULTS

AGGRESSIVITY TOWARDS OTHER CAR DRIVERS - Using the methods described above, logistic regression models of the injury risk and injury severity of the focus driver (ie. the driver of the "other" vehicle) were built separately as functions of, firstly, model and, secondly, the market group of the subject vehicle colliding with the vehicle of the focus driver.

The logistic regression models of the injury risk of focus drivers showed a number of factors to be statistically significant predictors. These were focus driver age and sex and the speed zone, along with the interaction between focus driver age and sex. In addition, the model of the colliding vehicle was also a statistically significant predictor of focus driver injury risk when added to the logistic regression model. This indicated that there is differential performance between vehicle models in terms of their aggressivity towards drivers of other vehicles so far as injury risk is concerned. In the same manner, when vehicle market group was substituted for vehicle model in the logistic regression equation, it was also a significant predictor of focus driver injury risk.

The logistic regression models of the injury severity of focus drivers showed the factors focus driver age and the speed zone to be statistically significant predictors. The model of the colliding vehicle was also a statistically significant predictor of injury severity as was the vehicle market group when substituted for vehicle model in the logistic regression equation.

Final estimates of vehicle aggressivity towards the drivers of other vehicles, formed by multiplying the estimated injury risk and injury severity components, were obtained for 56 different vehicle models (Cameron et al 1998).

Analysis by Market Groups - Table 2 summarises the estimated injury risk, injury severity and aggressivity ratings by the 8 broad market groups along with the estimated confidence limits on the aggressivity ratings. The estimated aggressivity rating is the expected number of vehicle drivers killed or seriously injured per 100 involved in two-car tow-away collisions where their vehicle impacts with one of the designated market group. Table 2 shows the four-wheel-drive vehicles to be the most aggressive towards drivers of other vehicles, with an average of 3.18 drivers being killed or seriously injured for every 100 tow-away crashes with a four-wheel-drive. Similarly, Table 2 shows sports cars to be the least aggressive towards drivers of other vehicles, with an aggressivity rating of 1.02.

Table 2 : Estimated Vehicle Aggressivity Towards Other Drivers, by Market Group

Market Group	No. of two-car crashes	Other Driver Injury Risk (%)	Other Driver Injury Severity (%)	Aggressivity Rating *	Overall rank order	Lower 95% confidence limit	Upper 95% confidence limit	Width of confidence interval
4 WHEEL DRIVE	3539	16.0	19.9	3.18	8	2.63	3.73	1.10
COMMERCIAL	4200	15.5	14.0	2.17	6	1.75	2.59	0.85
LARGE	29829	11.6	16.0	1.86	5	1.71	2.01	0.30
LUXURY	2728	11.8	15.1	1.77	4	1.29	2.26	0.97
MEDIUM	17652	10.4	14.3	1.49	3	1.31	1.66	0.35
PASSENGER VANS	2177	14.7	18.3	2.69	7	2.03	3.35	1.32
SMALL	19698	8.7	14.8	1.29	2	1.14	1.44	0.31
SPORTS	751	11.3	9.0	1.02	1	0.31	1.74	1.43

* Serious injury rate per 100 drivers of other vehicles involved in collisions with vehicles from the given market group

Statistically Significant Makes and Models - The estimated aggressivity ratings towards drivers of other vehicles for the 56 individual vehicle models rated ranged from a minimum of 0.23 to a maximum of 5.25 serious injuries per 100 tow-away crashes.

Of the 56 individual vehicle models for which an aggressivity rating was calculated, seven models had an aggressivity rating which was significantly less (better) than the overall average of 1.53 serious driver injuries per 100 tow away crashes. These seven vehicle models comprised three small car models, three medium car models and one sports car.

Four models had an aggressivity rating which was significantly greater (worse) than the overall average. These four models comprised one large car model, two four-wheel-drive models and one make of passenger vans.

AGGRESSIVITY TOWARDS UNPROTECTED ROAD USERS - A logistic regression model of the injury severity of unprotected road users was built as a function of, firstly, model and, secondly, broad market group of the vehicle colliding with the unprotected road user. Variations in the other influential factors listed above were adjusted in the model by including them as predictors of unprotected road user injury severity along with colliding vehicle model or market group.

The logistic regression model of the injury severity of unprotected road users showed a number of factors to be statistically significant predictors. These factors were the unprotected road user age and sex, the speed zone and the type of unprotected road user, along with interactions between speed zone and type of unprotected road user, speed zone and age of unprotected road user, and unprotected road user age and sex. In addition, the model of the colliding vehicle was also a statistically significant predictor of unprotected road user injury severity. As with the aggressivity towards drivers of other vehicles, the results indicated that there is differential performance between vehicle models in terms of their aggressivity towards unprotected road users so far as injury severity is concerned. In the same manner, when vehicle market group was substituted for vehicle model in the logistic regression equation, it was also a statistically significant predictor of unprotected road user injury severity.

As mentioned previously, it was not possible to estimate injury risk for unprotected road users as all those involved in reported crashes in the data available were injured. Hence the aggressivity rating for the unprotected road users was limited to the injury severity estimate. On this basis, aggressivity ratings toward unprotected road users were obtained for 86 different vehicle models (Cameron et al 1998).

Analysis by Market Groups - Table 3 summarises the aggressivity ratings by the 8 broad market groups along with the estimated confidence limits on the aggressivity ratings. The aggressivity rating is the expected number of unprotected road users killed or seriously injured per 100 injured in impacts with one of the vehicles from each designated market group. Table 3 shows the four-wheel-drive vehicles to be the most aggressive towards unprotected road users, with an average of 41.5 unprotected road users being killed or seriously injured for every 100 injured by these vehicles. Similarly, Table 3 shows medium cars to be the least aggressive towards unprotected road users, with an aggressivity rating of 31.2%.

Table 3 : Estimated Vehicle Aggressivity Towards Unprotected Road Users, by Market Group

Market Group	No. of injured Unprotected Road Users	Aggressivity towards Unprotected Road Users (%)*	Overall rank order	Lower 95% Confidence Limit	Upper 95% Confidence Limit	Width of Confidence Interval
4 WHEEL DRIVE	886	41.5	8	38.3	44.6	6.3
COMMERCIAL	1190	36.8	7	34.1	39.5	5.4
LARGE CARS	5989	31.3	2	29.8	32.8	3.0
LUXURY	810	34.0	5	30.9	37.1	6.2
MEDIUM CARS	3532	31.2	1	29.4	32.9	3.5
PASSENGER VANS	674	36.6	6	33.2	40.1	6.9
SMALL CARS	3948	32.4	3	30.7	34.1	3.4
SPORTS	258	32.8	4	27.9	38.1	10.2

* Serious injury rate per 100 unprotected road users injured in collisions with vehicles from the given market group

In general, within each market group, the average injury severity for unprotected road users is more than double that of vehicle drivers injured in impacts with the subject vehicles, highlighting the vulnerability of this road user group when involved in a crash.

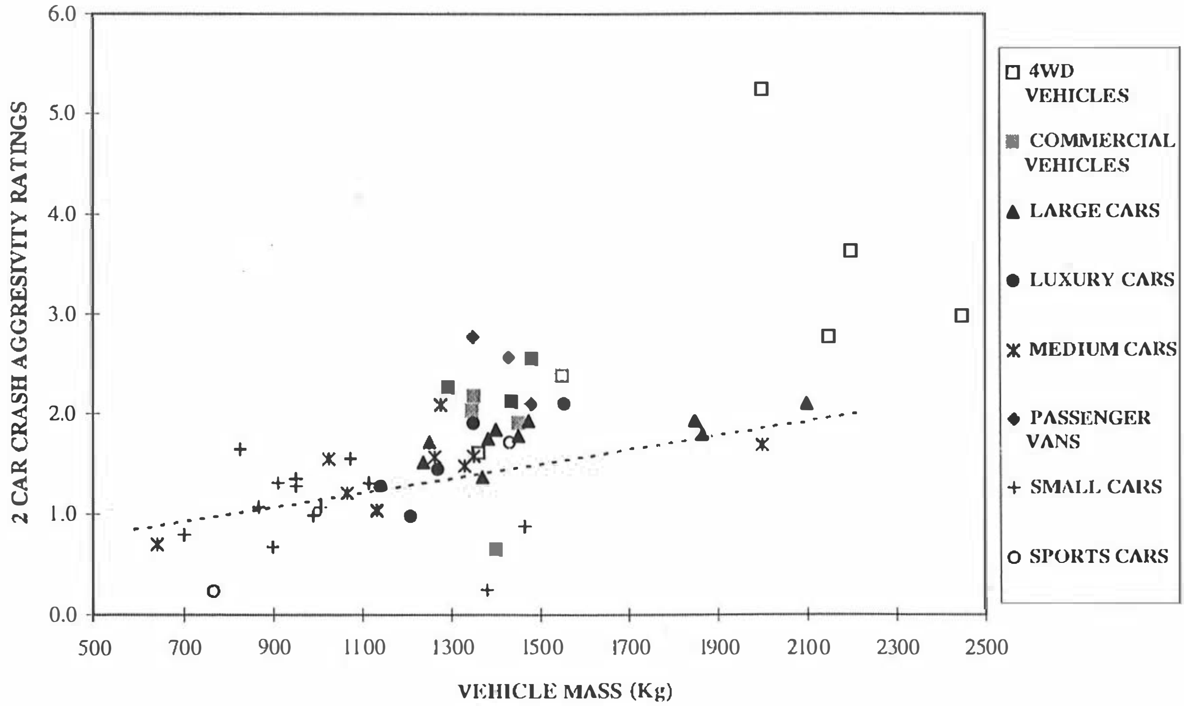
Statistically Significant Makes and Models - The estimated aggressivity ratings towards unprotected road users for the 85 individual vehicle models rated ranged from a minimum of 14.6 to a maximum of 46.6 serious injuries per 100 injured unprotected road users.

Three models had an aggressivity rating which was significantly less (better) than the overall average for the 85 models. These comprised two large car models and one medium car.

Eight models had an aggressivity rating which was significantly greater (worse) than the overall average. These comprised two small car models, four four-wheel-drive models and two makes of commercial vans.

RELATIONSHIPS BETWEEN AGGRESSIVITY, CRASHWORTHINESS AND VEHICLE MASS - Broughton (1996) and Cameron et al (1995) have noted a strong relationship between vehicle crashworthiness and mass, with heavier vehicles tending to display better crashworthiness. In the same manner, it might be expected that a mass relationship might exist for aggressivity. Figure 1 plots the estimated aggressivity rating towards other drivers against vehicle mass for the 56 models rated and shows that vehicles with higher mass tend to be more aggressive towards drivers of other vehicles.

Figure 1 : Estimated Vehicle Aggressivity Towards Other Drivers vs. Vehicle Mass

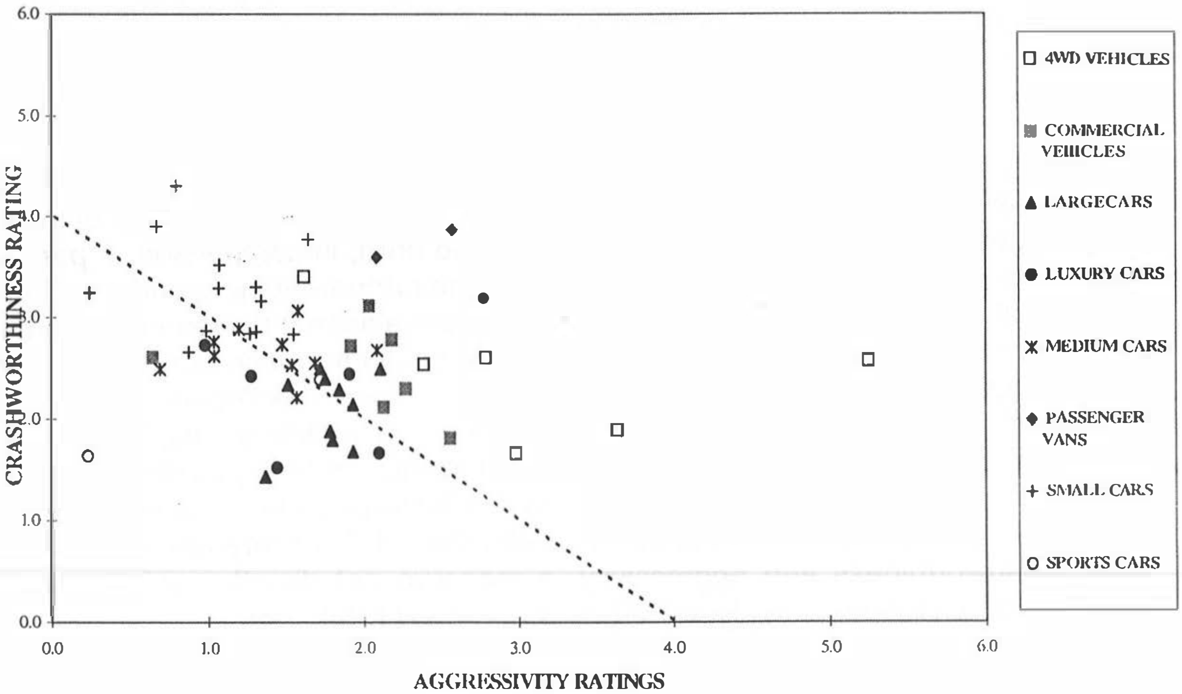


The dotted line in Figure 1 illustrates the relationship between aggressivity and vehicle mass. Some classes of vehicle tend to exhibit particularly high aggressivity even after accounting for mass effects (ie. those vehicles with points lying above the dotted line in Figure 1). The four-wheel-drive, passenger vans and commercial vehicles generally fall into this category.

The results also indicate that the subject vehicle mass (or the ratio of the mass of the subject vehicle to the mass of the other vehicle) could be included as a covariate in a logistic regression analysis similar to that described above. This analysis would allow the effects of vehicle design on aggressivity to be seen more clearly.

Aggressivity and Crashworthiness - In assessing the British vehicle safety indices, Broughton (1996) found a strong inverse relationship between the indices for crashworthiness and aggressivity. Figure 2 shows aggressivity towards other drivers plotted against crashworthiness for those vehicle models with both ratings (for both measures, high values are indicative of high risks of serious injury to a driver involved in a crash). As Figure 2 shows, the inverse relationship between the two measures is not particularly strong. The dotted line in Figure 2 represents the nominal inverse relationship between aggressivity and crashworthiness ratings with points above the line representing vehicle with relatively high aggressivity for their level of crashworthiness and points below the line representing vehicles with relatively low aggressivity for their crashworthiness performance. Four-wheel-drives, passenger vans and commercial vehicles are again the groups of vehicles which generally show relatively high levels of aggressivity for their level of crashworthiness.

Figure 2 : Estimated Vehicle Aggressivity Towards Other Drivers vs. Crashworthiness Rating



Absence of a strong relationship between the measures of aggressivity and crashworthiness suggests that the two quantities considered here are measuring two different aspects of a vehicle's safety performance. Whilst one would expect some relationship between the two measures given their common but opposite relationships with mass, the lack of a strong relationship suggests vehicle mass is only playing a small part in the aggressivity dimension relative to total vehicle safety design. The independence of these two measures does not seem to have been achieved to the same degree under other systems (UK Department of Transport 1995, Broughton 1996).

DISCUSSION

The methods developed and applied in this paper have allowed estimation of vehicle aggressivity ratings for Australian passenger vehicles with respect to both drivers of other vehicles and unprotected road users. Aggressivity is an important measure as, in conjunction with crashworthiness ratings, it enables assessment of the total safety of the vehicle fleet from the perspective of the protecting not only its own occupants in a crash but also road users external to that vehicle. Vehicle safety ratings in Australia to date have concentrated primarily on estimating the relative protection a vehicle provides to its own occupants. Consumer information has typically recommended that people purchase vehicles which offer maximum safety benefits to them as occupants without recourse to the risk the specific vehicles may pose to other road users. This study has demonstrated that this advice may not necessarily provide a net gain to society as a whole. One example is a recommendation for people to buy large four-wheel-drive vehicles based on their occupant protection performance without noting that these vehicles pose a high injury risk to other road users in a collision, a point particularly relevant if the vehicle is to be used in an urban environment where the likelihood of a collision with another road user is high. Whilst the issue of aggressivity may not be a high priority for vehicle consumers, the information should be valuable to both legislators and those promoting vehicle safety generally. The availability of vehicle aggressivity ratings in conjunction with crashworthiness ratings will allow these groups to focus legislation and consumer advice to achieve better total vehicle safety performance.

Whilst similar in concept to the aggressivity ratings developed overseas, the ratings developed here appear to be superior in a number of areas. One of the major advantages of the aggressivity ratings developed here, in comparison to particularly those described in Broughton (1994, 1996), is their apparent independence from the crashworthiness ratings. A high level of inverse correlation between crashworthiness and aggressivity ratings would diminish the additional information on safety provided by the aggressivity measure. The aggressivity ratings developed here, however, appear to provide largely independent information on vehicle safety. The reason for the independence of the two measures found in this study is possibly linked to the availability of non-injury crash data due to the tow-away crash reporting criteria in NSW. Non-injury crash data allows the estimation of the injury risk components of both crashworthiness and aggressivity, a measure not directly available from the data on injury crashes only described by Broughton (1994, 1996).

One drawback aggressivity ratings have in comparison to the crashworthiness ratings of Newstead et al (1997) is that they cover far fewer individual vehicle models. Aggressivity ratings for other drivers and unprotected road users estimated here cover only 56 and 85 vehicle models, respectively, whilst crashworthiness ratings based on almost the same data cover 120 individual models. The reason for the reduced model coverage in comparison to crashworthiness ratings stems from the fact that the aggressivity ratings, for reasons described above, are calculated from subsets of the total data used for crashworthiness calculation, namely crashes between two passenger vehicles manufactured later than 1982 and crashes with unprotected road users. Smaller quantities of data also compromise the precision of the aggressivity measures resulting in far fewer vehicles which can be differentiated as better or worse than the overall average in comparison to the differentiation obtained from crashworthiness ratings. These deficiencies highlight the need for further updates of the aggressivity ratings when additional data becomes available.

With the addition of the two measures of vehicle aggressivity developed in this paper, there are now three independent measures of the safety performance of Australian passenger vehicles derived from analysis of mass crash data. For simplicity of presentation and interpretation, particularly in the area of consumer safety advice, effort needs to be made to find a method of consolidating this information into a single measure of total vehicle safety, or some other cohesive method of summary presentation, which reflects overall vehicle safety. Combination measures could include an average of the three measures weighted by the relative involvement of the road user type to which each relates in past crashes involving the vehicle model concerned, treating crashworthiness as a safety benefit and aggressivity as a safety disbenefit. There are other approaches which could also be feasible. Further research needs to be undertaken to establish the most appropriate method of consolidation.

CONCLUSIONS

This paper has discussed the history and principles behind the estimation of vehicle aggressivity ratings. It has used these concepts to develop a framework for estimation of vehicle aggressivity ratings for Australian passenger vehicles. These methods have been successfully applied to estimate two different types of aggressivity ratings.

Firstly, ratings of aggressivity towards drivers of other passenger vehicles, measuring the risk of serious injury a vehicle poses to drivers of other cars with which it impacts, were calculated for 56 models of Australian passenger vehicles. Secondly, ratings of aggressivity towards unprotected roads users, namely pedestrians, motorcyclists and bicyclists, measuring the risk of serious injury a vehicle poses to these road users when injured in a crash, were estimated for 85 different vehicle models.

Estimated vehicle aggressivity towards drivers of other vehicles was found to have an increasing relationship with subject vehicle mass. It was also found to have little or no relationship with ratings of vehicle crashworthiness, demonstrating the independence of the two complementary measures.

REFERENCES

BROUGHTON, J. (1994), "The theoretical basis for comparing the accident record of car models". Project Report 70, Safety and Environment Resource Centre, Transport Research Laboratory, Crowthorne, Berkshire, U.K.

BROUGHTON, J. (1996), "The theoretical basis for comparing the accident record of car models". *Accident Analysis and Prevention*, Vol. 28, No. 1, pp. 89-99.

CAMERON, M.H., MACH, T., NEIGER, D., GRAHAM, A., RAMSAY, R., PAPPAS, M., and HALEY, J. (1992), "Vehicle Crashworthiness Ratings In Australia". *Proceedings, International Conference on the Biomechanics of Impacts*, Verona, Italy, pp. 105-119.

CAMERON, M.H., FINCH, C., NEWSTEAD, S., LE, T., GRAHAM, A., GRIFFITHS, M., PAPPAS, M., and HALEY, J. (1995), "Measuring Crashworthiness: Make/Model Ratings and the Influence of Australian Design Rules for Motor Vehicle Safety." *Proceedings, International Conference on the Biomechanics of Impacts*, Brunnen, Switzerland, pp. 297-310.

CAMERON, M.H., NEWSTEAD, S.V., and SKALOVA, M. (1996), "The Development of Vehicle Crashworthiness Ratings in Australia". Paper No. 96-S9-O-14, *Proceedings, 15th International Technical Conference on the Enhanced Safety of Vehicles*, Melbourne, Australia.

CAMERON, M.H., NEWSTEAD, S.V., and LE, C.M. (1998), "The Development and Estimation of Aggressivity Ratings for Australian Passenger Vehicles Based on Crashes During 1987-95." Monash University Accident Research Centre.

DEPARTMENT OF TRANSPORT (1995), "Cars: Make and Model: The Risk of Driver Injury and Car Accident Rates in Great Britain: 1993". Transport Statistics Report. London: Her Majesty's Stationery Office.

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

HOLLOWELL, W.T., and GABLER, H.C. (1996), "NHTSA's Vehicle Aggressivity and Compatibility Research Program". *Proceedings, Fifteenth International Technical Conference on the Enhanced Safety of Vehicles*, Melbourne.

HOSMER, D.W., and LEMESHOW, S. (1989), "Applied Logistic Regression". Wiley, New York.

LANGWIEDER, K., and FILDES, B.N. (1997), "Quality Criteria for the Safety Assessment of Cars: Report of two international workshops to determine the possibilities and limitations of safety rating systems". Büro für Kfz-Technik, Verband der Schadenversicherer e.V., Munich, Germany.

NEWSTEAD, S., CAMERON, M.H., and LE, C.M. (1997), "Vehicle Crashworthiness Ratings and Crashworthiness by Year of Manufacture: Victoria and NSW Crashes During 1987-95". Report No. 107, Monash University Accident Research Centre.