

## **AN INDEX FOR RATING THE TOTAL SECONDARY SAFETY OF VEHICLES FROM REAL WORLD CRASH DATA**

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### **ABSTRACT**

This study proposes a total secondary safety index for light passenger vehicles that rates the relative performance of vehicles in protecting both their own occupants and other road users in the full range of real world crash circumstances. The index estimates the risk of death or serious injury to key road users in crashes involving light passenger vehicles across the full range of crash types. The proposed index has been estimated from real world crash data from Australasia and was able to identify vehicles that have superior or inferior total secondary safety characteristics compared with the average vehicle.

A number of systems have been developed internationally to rate the secondary safety performance of vehicles from the analysis of real world crash data reported by police or in insurance claims databases. The major focus of most vehicle safety ratings systems developed has been on the relative performance of vehicles in protecting their own occupants (crashworthiness). Systems focused on crashworthiness include those developed in Sweden [Gustafsson, Hagg, Krafft et al., 1989], Great Britain [DfT, 1995], Finland [Tapio, Pirtala, & Ernvall, 1995] and Australia [Cameron, Finch, Newstead et al., 1995]. Generally, these systems measure either the risk or relative risk of injury or death and serious injury to a driver when involved in a crash reported to police. In all instances, the ratings systems attempt to measure injury outcomes only related to vehicle design. In order to achieve this, each of the ratings systems use techniques to adjust the estimated ratings for the effects of non-vehicle related factors that influence injury outcomes and that may vary between vehicles. Techniques used to adjust the ratings include logistic regression modelling and manual normalisation techniques. Ratings are published by vehicle make and model as consumer information on relative vehicle safety typically as a brochure or other hard copy publication or on internet web sites. Information on the Australian ratings is accessed widely on the internet and disseminated through the distribution of over 250,000 brochures annually. Many of the

institutions distributing the information report that it is their most popular source of consumer safety information.

In response to the growing importance of collision partner protection in crashes during the 1990s, some of the international vehicle safety ratings systems were extended to consider ratings of vehicle aggressivity. Broadly, aggressivity ratings measure the risk of injury or serious injury that a vehicle poses to road users other than its own occupants (including other vehicle drivers, pedestrians, motorcyclists and bicyclists) in a collision. The Finnish rating system has a measure of relative vehicle aggressivity towards other vehicle drivers [Huttula, Pirtala, & Ernvall, 1997]. The Australian vehicle safety rating system was also expanded to include a measure of relative vehicle aggressivity. Initially, two indices were developed in the Australian system separately considering other vehicle drivers and unprotected road users (pedestrians, cyclists and motorcyclists) [Cameron, Newstead, & Le, 1998]. This was later combined into a single index considering both other vehicle drivers and unprotected road users [Newstead, Watson, & Cameron, 2006]. The Australian aggressivity metric measures the risk of death or serious injury to drivers of cars or unprotected road users when involved in collisions with the model of car being rated for aggressivity. Like the Australian crashworthiness ratings, the aggressivity measure was adjusted for the effects of non-vehicle factors differing between the subject car models which may have affected injury outcome to the other road user. Adjustment was made by including measures of these other factors along with an indicator of vehicle model being rated in a logistic regression analysis. The Australian aggressivity ratings are published along side the crashworthiness ratings in the distributed brochure and on internet web sites of Australian and New Zealand motoring clubs and government road authorities. Media and consumer interest in both ratings sets is very high.

**THE NEED FOR A COMBINED INDEX** - The current presentation of the crashworthiness and aggressivity ratings for consumer information in Australia simply presents the two ratings side by side. This leaves the consumer to decide the relative importance of each rating in making a decision on vehicle safety priority in their purchasing decision. From a consumer information perspective, this might seem a good strategy as it allows the consumer to balance the relative priority they give to their own safety versus the safety of other road users on an individual basis. However, it may not be ideal from the perspective of trying to steer the vehicle fleet as a whole in the direction of optimum safety. This should be the overarching priority for safety advocates, regulators and the community as a whole. If consumers generally based their vehicle choices only on crashworthiness performance and largely ignored aggressivity, sub-optimal choices on a community wide safety basis may result. Similar sub-optimal choices may result if only

aggressivity were considered. A desire to optimise vehicle secondary safety on a whole-of-community basis highlights the need for an index which combines the crashworthiness and aggressivity performance of a vehicle into a single index. The goal is an index which captures the overall secondary safety of the vehicle in the most meaningful way for the environment in which it is driven and hence the crash circumstances to which it is exposed.

The international vehicle safety literature shows a paucity of effort in developing such an index. The only rating system to have given the concept serious consideration is that in Finland [Huttula et al., 1997]. The Finnish ratings include a total passive safety index which is essentially the sum of the crashworthiness and aggressivity measures for each vehicle. Deriving the total passive safety index in this way implicitly assumes that crashworthiness and aggressivity have equal weighting in the overall secondary safety performance of a vehicle. Whether this is the most appropriate approach is questionable since the relative balance of importance between crashworthiness and aggressivity will depend on the mix of crash circumstances the vehicle is exposed to. Furthermore, the Finnish total secondary safety rating only considered vehicle to vehicle crashes, ignoring single vehicle crashes and crashes involving unprotected road users, both crash types being significant contributors to total road trauma in Australia and New Zealand.

A more detailed approach to the issue of estimating total vehicle passive or secondary safety has been explored in the context of the Australian ratings [Newstead, Delaney, Watson et al., 2004; Newstead, Watson, Delaney et al., 2004]. This work was based on analysis of Australian crash data and commenced by identifying the four primary crash types in which light passenger vehicles were involved and identified the principal injury outcomes of interest in the crash. These are summarised in Table 1 along with the proportionate representation of each of these crash types amongst all crashes involving light passenger vehicles. For light passenger to heavy vehicle crashes, only the injury outcome to the light vehicle driver is relevant as the heavy vehicle driver is typically uninjured in the crash. In crashes between unprotected road users and light passenger vehicles, the light passenger vehicle driver is usually uninjured. As for the calculation of the individual crashworthiness and aggressivity ratings, occupants of vehicles other than the driver are not considered since reported data on uninjured non-drivers in the vehicle is often incomplete.

Table 1 - Crash types, injury outcome focus and percentage representation of major crash types involving light passenger vehicles

<b>Crash Types</b>	<b>Focus injury outcomes</b>	<b>Proportion of all light passenger vehicle crashes</b>
1) Passenger Vehicle to Passenger Vehicle	Injury outcome to the driver of each light vehicle (crashworthiness and aggressivity)	45.3%
2) Single Passenger Vehicle	Injury outcome to the light vehicle driver (crashworthiness)	28.9%
3) Passenger Vehicle to Heavy Vehicle	Injury outcome to the light vehicle driver (crashworthiness)	16.0%
4) Passenger Vehicle to Unprotected Road User	Injury outcome to the unprotected road user (aggressivity)	9.7%

The total secondary safety index defined by Newstead, Delaney, Watson et al (2004) was calculated by broad market group of vehicle and is an average of four individual crashworthiness or aggressivity based measures based on the focus injury outcomes in Table 1 weighted by the proportionate representation of each of the four crash types. As such, it represents the overall secondary safety performance of a vehicle in protecting all road users involved in the full range of crashes and reflecting the relative incidence of each major crash type. Constructing the total secondary safety index in this way was similar in basic principle to the approach used in the Finnish system. However it differs in the fact that it gives appropriate weighting to each aspect of a vehicle's secondary safety performance by weighting each component according to its relevance in Australian real world circumstances.

The index of Newstead, Delaney, Watson et al (2004) however had some limitations related to the manual construction of the index from its components. First, there had to be sufficient data to estimate each of the component safety measures comprising the index. In the demonstration of the methodology this meant results could only be obtained by broad market group of vehicle and not for individual makes and models of vehicle. Second, estimates of statistical confidence on the index could not be estimated due to its complex nature. Both these difficulties highlighted the need for development of an integrated total secondary safety index that could be estimated by vehicle make and model with associated estimates of statistical confidence. The development of such an index was the focus of this study. The aim was

to produce a total secondary safety index that represented the combined crashworthiness and aggressivity performance of a vehicle over the typical mix of crash circumstances to which Australian vehicles are exposed. Like the crashworthiness and aggressivity measures, the aim for the total secondary safety index was to represent the influence of vehicle factors alone on injury outcomes, controlling for differences in demographics of those involved in the crash, the crash circumstances and the crash types between different vehicle models or market groups being rated.

## DATA

CRASH DATA - Police reported crash data from Australia and New Zealand, used to produce the crashworthiness and aggressivity ratings of Newstead, Watson and Cameron (2006) and covering vehicles manufactured over the period 1982-2004 and crashing during the years 1987-2004, was used in the estimation of the total secondary safety index. Key crash types on which the total safety index is based were identified in the crash data. *Collisions with Heavy Vehicles*: Data on light passenger vehicles involved in two-vehicle collisions with heavy vehicles covered 77,545 light passenger vehicle drivers. *Collisions Involving Unprotected Road Users*: Data on unprotected road users involved in a collision with a single light passenger vehicle covered 83,995 injured unprotected road users. Uninjured road users are generally not reported to police. *Single Vehicle Collisions*: The data for single vehicle collision covered 349,182 light passenger vehicle drivers involved in a single vehicle crash. *Multi Vehicle Collisions*: Data covered 2,079,912 vehicles were involved in a collision involving two or more light passenger vehicles.

VEHICLE MODEL IDENTIFICATION AND GROUPING – Vehicle makes and models in the data were identified either from detailed make and model descriptions available in the vehicle registers from each jurisdiction providing crash data, or by a process of Vehicle Identification Number (VIN) decoding using VINs also obtained from the vehicle registers. Vehicles were then classified into make and model groupings using year of manufacture to create clusters with as homogeneous engineering and equipment specification as possible.

Each make and model grouping was also classified into one of 12 market groups for analysis. They comprised: 7 classes of regular passenger car; Light (< 1100kg tare mass), Small (1100-1250kg tare mass), Medium (1250-1400kg tare mass), Large (>1400kg tare mass), People Movers (seating capacity > 5 people), Sports (coupe or convertible) and Luxury (highly specified); 3 classes of four wheel drive (4WD) vehicle (also known as Sport Utility Vehicles); 4WD Compact (<1700kg tare mass), 4WD Medium (1700kg-2000kg tare mass) and 4WD Large (>2000kg tare mass); and 2 classes of light commercial vehicle; Van and Utility.

## MEASURES AND METHODS

### DEFINING THE TOTAL SECONDARY SAFETY INDEX -

The concept of the total secondary safety index developed in Newstead, Delaney, Watson et al (2004) forms the basis of the integrated single measure of total secondary safety developed here and has some inherent similarities to the Australian crashworthiness and aggressivity metrics. Like the initial index of Newstead, Delaney, Watson et al (2004), the integrated total secondary safety index is formulated by considering the four major crash types involving light passenger vehicles and the most relevant injury outcomes in those crashes. Table 2 summarises the key elements necessary to calculate the total secondary safety index. The table is categorised by each of the four major crash types considered, giving the focus crash participants whose injury outcomes are considered in the index and representations of the key injury counts by injury severity level. The final column of Table 2 gives the proportion of the total crash population represented by each crash type for the crash population being considered.

Table 2 - Light passenger vehicle crash types, injury outcome counts and percentage representation components for formulating the total secondary safety index.

Crash Type	Focus Crash Participant	No. Involved	No. Injured	No. Killed or Seriously Injured	Proportion of Total Crash Population
1. Passenger Vehicle to Passenger Vehicle	Focus light vehicle driver	$E_{lf}$	$I_{lf}$	$S_{lf}$	$p_1$
	Other light vehicle driver	$E_{lo}$	$I_{lo}$	$S_{lo}$	
2. Single Passenger Vehicle	Light vehicle driver	$E_2$	$I_2$	$S_2$	$p_2$
3. Passenger Vehicle to Heavy Vehicle	Light vehicle driver	$E_3$	$I_3$	$S_3$	$p_3$
4. Passenger Vehicle to Unprotected Road User	Unprotected road user	$N/A$	$I_4$	$S_4$	$p_4$

*N/A – Not fully reported in police crash records*

Heavy vehicle drivers are typically not injured in crashes with light passenger vehicles and are hence not considered in the total secondary safety index. Similarly, drivers of the light passenger vehicle are generally not injured in crashes with unprotected road users and have not been included in formulating the index. Vehicle occupants other than drivers have not been considered as they are often not recorded by police in their crash reports unless injured. Similarly, crashes involving uninjured unprotected road users are generally not reported to police and hence the total number of unprotected road users involved in crashes is unknown. The ‘focus’ light vehicle driver in Table 2 refers to the driver of the vehicle being rated whilst the ‘other’ vehicle is the collision partner.

Like the Australian crashworthiness and aggressivity measures, the total secondary safety index is defined as the product of an injury risk component and an injury severity component. The need to define a two component measure is necessary to be able to make best use of the police reported crash databases in New Zealand and Victoria that record only crashes involving injury. It is not possible to determine injury risk from these databases.

The measure of total secondary safety injury risk,  $R_T$ , is defined by Equation 1. It measures the average risk of injury across all key participants in a crash involving a light passenger vehicle weighted by the relative crash involvement of each participant type across the entire crash population. Since unprotected road users are generally injured in crashes reported to police, they are not included in the injury risk measure.

$$R_T = p_1 \left( \frac{I_{1f} + I_{1o}}{E_{1f} + E_{1o}} \right) + p_2 \frac{I_2}{E_2} + p_3 \frac{I_3}{E_3} \quad (1)$$

The corresponding total secondary safety injury severity measure,  $S_T$ , is defined by Equation 2. It measures the average risk of death or serious injury given some injury was sustained across all key participants in a crash, weighted again by the relative exposure of each participant type across the entire crash population.

$$S_T = p_1 \left( \frac{S_{1f} + S_{1o}}{I_{1f} + I_{1o}} \right) + p_2 \frac{S_2}{I_2} + p_3 \frac{S_3}{I_3} + p_4 \frac{S_4}{I_4} \quad (2)$$

The integrated total secondary safety index,  $T$ , is defined to be the product of the injury risk and injury severity components as given by Equation (3). It measures the average risk of death or serious injury in crashes involving a light passenger vehicle across all key participants in

the crashes, weighted again by the relative exposure of each participant type across the entire crash population. It can be estimated for individual vehicle models, by vehicle market groups or for the fleet as a whole as desired, with a table of the form of Table 2 being derived for each entity at the level of disaggregation desired.

$$T = R_T \times S_T \quad (3)$$

**ESTIMATION OF THE INDEX AND ADJUSTMENT FOR NON-VEHICLE RELATED FACTORS** - Like the Australian crashworthiness and aggressivity indices, the aim for the integrated total secondary safety index was that it reflect only the influence of the vehicle on injury outcome and not factors external to the vehicle such as key participant or crash characteristics. Consequently, there was a need to compensate for differences in these key non-vehicle related factors that existed between vehicle models and market groups. Logistic regression analysis was utilised to produce total secondary safety ratings appropriately adjusted as far as possible for the influence on non-vehicle related factors on injury outcome. For estimation of the total secondary safety ratings, factors in the logistic model included the available non-vehicle factors influencing injury outcome. These were driver or unprotected road user age and gender, year and jurisdiction of crash, speed limit at the crash location and broad crash configuration (from Table 2).

Belt use was considered as an adjustment factor in the logistic regression models. Although it was found to be a significant predictor of injury outcome, it did not alter the ratings estimates. This is because significant variations in belt use are found between particular makes and models or market groups of vehicles in Australia and New Zealand. Alcohol use was not available in the full data set used for the analysis. However, like belt use, it is unlikely alcohol use is associated with specific makes and models or market groups of vehicles meaning the estimated ratings would not be changed if this was included as an adjustment factor. Urban or rural crash environment was highly correlated with speed limit so both factors could not be included together in the model for reasons of high co-linearity.

In practice, each record in the data used for logistic modelling represented a driver or unprotected road user involved in a collision with a light passenger vehicle. A dichotomous injury outcome variable was coded for each case with coding dependent on whether injury risk or severity was being estimated. For each case a profile of covariates giving the non-vehicle factors associated with the person were also included in the data. These co-variables and their interactions were included in the logistic models along with a categorical variable indicating vehicle model or market group. A stepwise model selection procedure was used to



identify the covariates and their interactions significantly associated with injury outcome. The co-efficient of the vehicle model or market group categories in the logistic regression model represented the relative total secondary safety injury risk or injury severity for each vehicle with the standard errors of these coefficients used to derive confidence limits on the ratings estimates using techniques described in Newstead, Watson and Cameron (2006). Separate logistic models were estimated for the total secondary safety injury risk and injury severity component measures. All data were analysed using the Logistic Regression procedure of the SAS statistical package [SAS, 1999].

Since the analysis potentially included 2 drivers from the same crash in a light vehicle to light vehicle crash, an assumption implicit in the logistic modelling process was that, given the level of impact severity of the crash represented by non-vehicle factors in the logistic model, it was assumed that the injury outcome of the two drivers was independent. This assumption was considered reasonable since the estimated crashworthiness and aggressivity of vehicles rated by Newstead, Watson and Cameron (2006) appear to be essentially independent. Each of these measures focuses heavily on the injury outcome of each separate driver in a two vehicle crash.

## **RESULTS**

**TOTAL SECONDARY SAFETY INJURY RISK** - Total secondary safety injury risk was estimated from the data on 3,209,062 road users involved in tow-away crashes as light vehicle drivers in Australia during 1987-2004. Each of the covariates age, sex, speed limit at crash location, jurisdiction, year of crash and crash configuration along with a large number of first and second order interactions between these factors were identified as significant predictors of injury risk by the stepwise logistic modelling process for total safety injury risk.

The average injury rate for involved drivers or unprotected road users in crashes was 17.38 per 100 involved. Adjusted estimates of total secondary safety injury risk and 95% confidence limits were derived by logistic regression for 357 individual car models and each of the 12 market groups. Injury risk ranged from 6.38% to 33.96% for specific vehicle models whilst the estimated injury risk for each market group ranged from 15.23% for the luxury vehicles to 19.35% for the light car market group.

**TOTAL SECONDARY SAFETY INJURY SEVERITY** - The data used to estimate total secondary safety injury severity covered 576,610 injured road users. Each of the covariates age, sex, speed limit at crash location, jurisdiction, year of crash and crash configuration along with a large number of first and second order interactions between these factors were also identified as significant predictors of injury severity by the stepwise logistic modelling process.

The average injury severity for injured light vehicle drivers or unprotected road users in the data analysed was 22.18 killed or hospitalised drivers or unprotected road users per 100 injured. Estimates of injury severity and confidence limits were derived by logistic regression for the 357 individual car models and the 12 market groups. They ranged from 6.70% to 54.19% for specific vehicle models and from 20.99% for the compact four wheel drive vehicles to 25.38% for the large four wheel drive car market group

**TOTAL SECONDARY SAFETY INDEX** - The total secondary safety index for each car model and market group was obtained for each of the 357 car models and 12 market groups by multiplying the individual injury risk and injury severity estimates. Because each of the two components had been adjusted for the confounding non-vehicle related factors, the resultant total secondary safety index was also adjusted for the influence of these factors. Each total secondary safety rating is an estimate of the true risk of a light vehicle driver or unprotected road user being killed or admitted to a hospital in a crash.

Table 3 gives a summary of the estimated ratings for each of the 12 defined vehicle market groups. It shows the estimated injury risk and severity components, and the resulting total secondary safety index with upper and lower 95% confidence limits, and the width of the 95% confidence limit. The relative ranking of the total secondary safety index on each market group is also given in Table 3.

Table 3 - Estimated Vehicle Total Secondary Safety by Market Grouping

Market Group	Injury risk (%)	Injury severity (%)	Total Secondary Safety Index*	Overall rank order	Lower 95% C.L.	Upper 95% C.L.
<b>Overall Average</b>	<b>17.38</b>	<b>22.18</b>	<b>3.85</b>			
COMPACT 4WD	17.97	20.99	3.77	6	3.56	3.99
MEDIUM 4WD	16.46	21.95	3.61	3	3.39	3.85
LARGE 4WD	16.35	25.38	4.15	10	3.99	4.32
VAN	18.97	22.40	4.25	11	4.07	4.44
UTE	16.80	23.37	3.92	7	3.82	4.03
LARGE	16.48	21.74	3.58	2	3.53	3.64
LUXURY	15.23	21.20	3.23	1	3.13	3.33
MEDIUM	17.38	21.32	3.71	4	3.63	3.78
PEOPLE MOVERS	18.56	22.28	4.14	9	3.94	4.34
LIGHT	19.35	22.05	4.27	12	4.17	4.36
SMALL	17.73	21.27	3.77	5	3.70	3.84
SPORTS	17.59	22.42	3.94	8	3.79	4.11

\* - Serious injury rate per 100 road users involved in crashes involving the market group vehicles

Ratings by Make and Model – total secondary safety ratings were obtained for 357 different makes and models of vehicles grouped by years of manufacture with similar specification. Since the purpose of this paper is to articulate the concept of the total secondary safety rating and to demonstrate the efficacy of its estimation on real world data, results by individual make and model which have been calculated are not provided in this paper due to space restrictions. Table 3 demonstrates the estimated rating by broad market group of vehicle and shows significant difference in total secondary safety performance between various vehicle market groups. A further interest in assessing the efficacy of the rating is whether the index can differentiate the total secondary safety performance of individual vehicle models. To assess this, ratings by make and model and their 90% confidence limits were used to judge whether the true risk of death or hospitalisation associated with a specific model car involved in a tow-away crash were statistically different from the average rating across all models. An upper limit below the average is indicative of superior performance, whereas a lower limit above the average suggests inferior performance. Identification of vehicles with a total secondary safety rating statistically better and worse than average would prove the ability of the index to differentiate performance by make and model to at least some degree.

Sixty-four vehicle models had an index representing evidence of superior total secondary safety based on their upper 90% confidence limits being less than the average rating. They comprised 3 Compact 4WDs, 3 Medium 4WDs, 1 Utility, 1 Van, 9 Large cars, 18 Luxury cars, 6 Medium cars, 3 People Movers, 1 Light car, 15 Small cars and 4 Sports cars. Seventy-five models had indices representing evidence of inferior total secondary safety based on their lower confidence limits being greater than the average rating. They comprised 4 Compact 4WDs, 1 Medium 4WD, 3 Large 4WDs, 6 Vans, 7 Utilities, 3 Large cars, 4 Luxury cars, 6 Medium cars, 3 People Movers, 19 Light cars, 9 Small cars and 10 Sports cars. This comparison confirms the ability of the index to differentiate vehicle total safety performance at a vehicle model level. It also shows that although there is a tendency for some market groups to have vehicles that perform better or worse than average on the index, within each market group there is significantly different estimated total secondary safety performance between specific vehicle models.

Comparison of Crashworthiness, Aggressivity and the Total Secondary Safety indices - Figure 1 plots vehicle models' crashworthiness ratings against their total secondary safety index. The solid lines on the chart are the average value for each index. Figure 1 shows that a strong relationship exists between crashworthiness and total secondary safety, reflecting that crashworthiness is relevant to injury outcome in all types of crashes involving light vehicles excluding those with unprotected road users (see Table 1). In contrast, Figure 2 shows a much weaker relationship between aggressivity and total secondary

safety, reflecting that aggressivity is only relevant to injury outcome in crashes between 2 light vehicles and crashes involving unprotected road users.

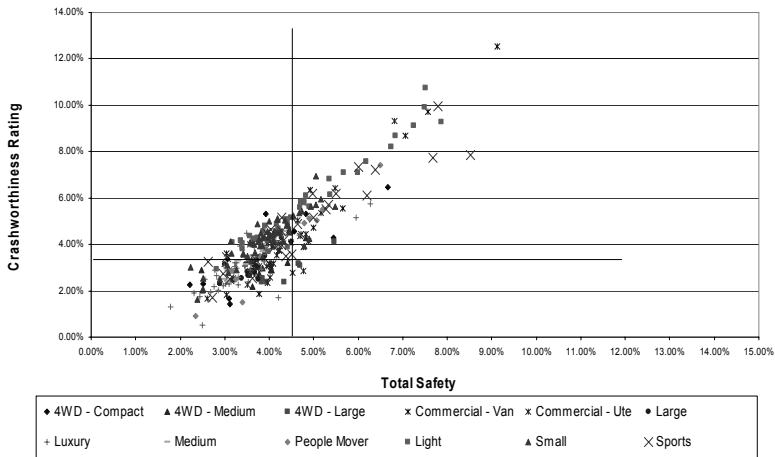


Figure 1 - Crashworthiness vs Total Secondary Safety

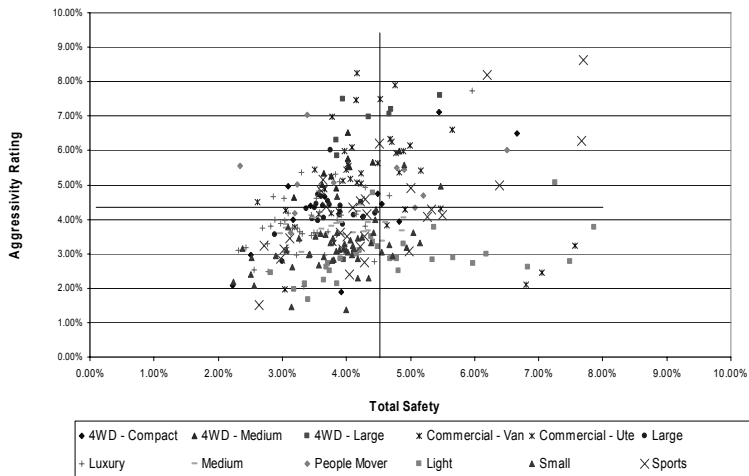


Figure 2 - Aggressivity vs. Total Secondary Safety

Table 4 summarises the estimated crashworthiness and aggressivity ratings from the safety ratings of Newstead, Watson and Cameron (2006) for each of the 12 defined vehicle market groups beside the total secondary safety index by market group along with the rank orderings within each index. It confirms the observations made from Figures 1 and 2 that the rank order of the market groups within the new total secondary safety index are consistent with the rankings suggested

by the crashworthiness measure, but with a moderating effect on the total secondary safety index dependent on the aggressivity of the vehicle. In other words vehicles with high aggressivity display a shift in their ranking for crashworthiness towards higher (or worse) total secondary safety ranking. For example, large four-wheel drives have shifted notably in their ranking from a 1 in the crashworthiness market group rankings to a ranking of 10 across the market groups for total secondary safety reflecting their high aggressivity.

Table 4 - Estimated Vehicle Crashworthiness by Market Grouping

Market Group	Crashworthiness Rating*	Overall rank order	Aggressivity Rating *	Overall rank order	Total Secondary Safety Index*	Overall rank order
<b>Overall Average</b>	<b>3.78</b>		<b>3.91</b>		<b>3.85</b>	
COMPACT 4WD	3.88	7	3.60	6	3.77	6
MEDIUM 4WD	2.98	2	4.72	9	3.61	3
LARGE 4WD	2.92	1	6.09	12	4.15	10
VAN	4.17	9	5.02	11	4.25	11
UTE	3.58	5	4.75	10	3.92	7
LARGE	3.43	4	3.74	7	3.58	2
LUXURY	3.07	3	3.38	4	3.23	1
MEDIUM	3.86	6	3.28	3	3.71	4
PEOPLE MOVERS	4.38	11	4.42	8	4.14	9
LIGHT	5.19	12	2.66	1	4.27	12
SMALL	4.27	10	2.85	2	3.77	5
SPORTS	4.12	8	3.51	5	3.94	8

\* Serious injury rate per 100 road users involved in crashes involving the market group vehicles

## DISCUSSION

The motivation for developing an index of total secondary safety for light passenger vehicles stemmed from an identified need to find an appropriate summary measure of the crashworthiness and aggressivity ratings that had been developed previously. Past presentation of the crashworthiness and aggressivity ratings has simply presented the ratings for each vehicle side by side and allowed consumers to balance the relative weight they give each in their vehicle purchasing decision. The general aim of the total secondary safety index was to summarise the combined crashworthiness and aggressivity measures in a way that best reflected the relative importance of each component in real world crash circumstances. By constructing the total secondary safety

index as a weighted average of injury outcome probabilities in a range of relevant major crash types involving light passenger vehicles and weighting each component by the relative incidence of that crash type, the index developed represents an objective and relevant summary.

By having a single index estimated in a single integrated analysis, it has allowed total secondary safety to be considered on a vehicle by vehicle basis with statistical confidence limits placed in the estimates. This is in contrast to the original total secondary safety index developed by Newstead, Delaney, Watson et al (2004). Although constructed on the same premise, that index was estimated in a piecewise fashion meaning it could only be considered by broad vehicle market group and was difficult to estimate statistical confidence limits for. One advantage of the original index though was that it enabled the relative performance of each vehicle market group in each major crash type to be seen explicitly, something not possible with the integrated single measure.

Comparison of the total secondary safety index with the crashworthiness and aggressivity estimates gives insight into the relative importance of the two separate measures in determining overall vehicle secondary safety performance. Figures 1 and 2 and Table 4 show the total vehicle secondary safety index is much more strongly associated with the crashworthiness measure than the aggressivity measure. This is as expected given that a vehicle's crashworthiness performance is relevant in a wider range of crash types than is its aggressivity. Specifically, crashworthiness is relevant in all crashes except crashes involving unprotected road users. In comparison, aggressivity is only relevant in crashes involving another light passenger vehicle or unprotected road user. This comparison highlights how the total safety index weights the crashworthiness and aggressivity performance in a way most appropriate to the crash types represented in the total crash population. However, this means the total secondary safety index will to a large degree be dependent on the distribution of crash types in the jurisdiction where the rated vehicle set is exposed. Consequently, the total safety index most relevant to one country might not be the most relevant to another if their crash type distributions are fundamentally different.

When considering market group based results, Table 2 shows luxury and large cars to have the best (lowest) total safety index of the 12 market groups considered. In contrast, light vehicles and commercial vans have the poorest overall secondary safety performance (highest index). It is interesting to note that the best and worst market groups for total secondary safety differ by only a factor of 1.32. In contrast, the crashworthiness and aggressivity rating differ between best and worst market groups by factors of 1.78 and 2.29 respectively. Both the crashworthiness and aggressivity indexes are dependent on vehicle mass with heavier cars generally having better crashworthiness but higher aggressivity with the opposite for lighter cars. The mass relationship

tends to heighten the spread of ratings between vehicle market groups which are broadly defined on a mass basis. Since the direction of the mass relationship is generally opposite between the crashworthiness and aggressivity ratings, combining them in the total secondary safety index will at least to some degree cancel out the mass effect, thus explaining the lower range of total secondary safety values estimated across the market groups. However, the total safety ratings may still have some mass dependency although this has not been examined here as it was considered of secondary importance.

One important limitation of the total secondary safety index, like the Australian and New Zealand crashworthiness and aggressivity measures, is that they are based only on the injury to drivers of light passenger vehicles. They do not consider the injury outcomes of other vehicle occupants. The reason for this is that vehicle occupants other than the driver are often not recorded by police when they are not injured. Consequently, injury risk amongst other vehicle occupants is difficult to estimate. Interrogation of the crash data used for the analysis showed that in over 95% of crashes, the driver was the most seriously injured occupant in the vehicle. This is largely because in a large number of cases the driver is the only occupant of the vehicle (average vehicle occupancy rates in Australia are about 1.4 people) as well as the driver having an extra contact source in the steering wheel. Whilst this means that the ratings focus on the most relevant occupant on the vehicle for injury outcome, it is acknowledged that expanding the ratings to consider all vehicle occupants, if it was possible, may yield slightly different results. In particular, it would give a higher weighting to occupant protection performance for those vehicle classes that typically have higher occupancy rates such as large cars and people movers.

The development of a third index of vehicle secondary safety in addition to the established crashworthiness and aggressivity ratings raises questions about what is the most appropriate and valuable information for consumers, regulators and vehicle safety advocates. For vehicle regulators and safety advocates, the total secondary safety index possibly represents the most relevant measure of vehicle secondary safety performance as it encapsulates the total performance of a vehicle in preventing serious injury outcome to all road users involved in crashes involving the specific vehicle. The total secondary safety index is the most relevant to developing policy to optimise the safety of the light vehicle fleet. Optimising on crashworthiness or aggressivity criteria alone will not necessarily produce the safest vehicle fleet. However, the crashworthiness and aggressivity components are still important separate measures to identify those characteristics of a vehicle leading to good performance in each dimension. Furthermore, the results of this study identify that optimising crashworthiness performance in the Australasian setting will lead to faster and wider spread gains than optimising for reduced aggressivity.

The popularity of consumer information on relative vehicle secondary safety performance has typically been very high in Australia and New Zealand. Over 250,000 brochures detailing the estimates of vehicle crashworthiness and aggressivity in a star rating type format are distributed across Australia and New Zealand each year. Information is also made available on auto club and government road authority web sites and receives many hundreds of thousands of hits each year. These figures demonstrate a high interest by consumers in information assessing vehicle secondary safety performance. One possible means of communicating the total secondary safety rating to consumers would be to add this as a third rating in the distributed brochure and web based material. It could be tagged as an 'overall performance rating' summarising the combined crashworthiness and aggressivity performance.

Presenting all three indices of vehicle secondary safety now available for consumer information together might create some confusion amongst consumers regarding which one is most relevant. Some would advocate that the consumer should be given each dimension of safety performance independently and be allowed to choose the most appropriate balance of crashworthiness and aggressivity themselves based on their personal circumstances and opinions. From a whole of society perspective, this may not lead to the best overall outcomes. Advocating use of the total secondary safety index as the primary consumer focus is much more likely to lead to better vehicle safety choices for society as a whole. Further careful consideration needs to be given to the most appropriate and effective way to present and market the three safety indices for consumer information. The ultimate usefulness of the new index to consumers also needs to be established.

## **CONCLUSIONS**

This study has been able to successfully develop a single integrated measure of total secondary safety of the light passenger vehicle fleet. The index measures the average risk of death or serious injury to light passenger vehicle drivers and unprotected road users (pedestrians, cyclists and motorcyclists) when involved in a crash with a light passenger vehicle, to a degree of accuracy represented by the confidence limits of the index in each case. It provides an overall summary of the combined crashworthiness and aggressivity performance of a vehicle weighted by the relevance of each component in real world crash situations. As far as possible, the index has been adjusted for a range of non-vehicle related factors known to affect injury outcome. Unlike previous attempts to develop such an index, the new total secondary safety index reflects vehicle secondary safety performance in single vehicle crashes and crashes with vulnerable road users such as pedestrians and bicyclists as well as in vehicle to vehicle crashes.



Applied to records of crashes reported to the police in four Australian states and New Zealand from 1987 to 2004, total secondary safety index estimates and their associated 95% confidence limits were obtained for 357 light passenger vehicle models classified into 12 market groups. They were sufficiently sensitive to be able to identify 139 models of passenger cars, four-wheel drive vehicles, passenger vans and light commercial vehicles that have superior or inferior total secondary safety characteristics compared with the average vehicle.

The index developed serves as a valuable summary of overall secondary safety of light passenger vehicles both for consumer information as well as for regulators and vehicle safety advocates in identifying and promoting vehicle safety characteristics that optimise overall secondary safety.

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