MASS DATA EVALUATION OF THE IMPORTANCE OF STRUCTURAL AND MASS RELATED AGGRESSIVITY

Anders Kullgren, Folksam Research, Sweden
Anders Lie, Swedish National Road Administration and Karolinska Institutet, Sweden
Claes Tingvall, Swedish National Road Administration, Sweden, and Monash University, Australia
Paper Number: 172

ABSTRACT

The problem of incompatibility between different car types has become an important issue in the society. In two-car crashes, the aggressivity to the other vehicles is a factor often mentioned. In this study aggressivity is defined as the influence on injury outcome in the other vehicle due to differences in car structure and mass of the studied vehicle. The study was based on police reported two-car collisions in Sweden. The influence of car mass and structure on driver relative injury risk was for some vehicle categories analyzed with a new developed technique where the influence of mass and structure was separated.

SUVs were found to have 32% higher mass factor and 23% higher structural aggressivity factor than the average value, resulting in a 62% higher total aggressivity factor than the average. MPVs were found to have 3% higher structural aggressivity factor than average, while the mass factor was 28% higher than average, resulting in 32% higher total aggressivity than that of the average car. It was also found that small cars had higher structural aggressivity factor than larger cars among the family car categories. Only small differences in the structural aggressivity factor was found for cars with different year of introduction, while an increase in the mass factor of approximately 10% between 1970 and 1995 was found. Only a small difference in the structural aggressivity factor was found for cars with different Euro NCAP star rating.

INTRODUCTION

Regarding road traffic safety, crash compatibility in two-vehicle crashes has become an issue of increased interest, especially in countries with a varied car population. The differences mainly concern vehicle mass and structure, such as vehicle height as well as stiffness and homogeneity of the front-end structure. The differences in structure and mass increase as new car types are launched. To date in Sweden car mass varies between 700 kg and 2,500 kg for family cars (Lie and Tingvall 2000).

The relationship between vehicle mass and stiffness has been studied from the US NCAP tests over the past 14 years. In average Pickups, Vans and SUVs were found to be much stiffer than passenger cars, although the stiffness of these vehicles was found to have decreased during this period. Also the peak deceleration was found to decrease, while the pulse duration was found to increase for these vehicles during this time period (Parker et al. 1999).

In studies based on real-life collisions, bonnet height, ground clearance and higher longitudinal frame members have been found to influence the injury outcome in the collision partner, especially in side impacts (Zobel 1998, Wykes et al. 1998). In another study comparing the influence of different parameters related to structure on injury risk in frontal offset car-to-car crash simulations, it was found that stiffness had the largest influence on injury risk, followed by bumper level and mass (Buzeman-Jewkes 1998).

Many studies have shown the influence of mass on injury and fatality risks in two-car crashes, see for example IIHS (1999) and Hägg et al. (1992). Both mass and structure influence the injury outcome in the vehicle studied and in the vehicles it is colliding with. IIHS (1999) has also shown that in two-vehicle crashes, there are approximately twice as many fatalities in the studied vehicle in collisions with pickups and utility vehicles than car-to-car crashes for vehicles of similar mass. This fact indicates that the front-end design of a car plays an important role for the injury outcome in the collision partner.

The influence of mass and structure on the injury outcome in the other vehicle can be regarded as the aggressivity of a car model. Many studies are in use aimed at rating the aggressivity of vehicles in two-car crashes based on real-life injury outcomes (see for example NHTSA 1999, Huttula et al. 1997, Cameron et al. 1997). The studies in use rate aggressivity in different ways. The ratings presented by NHTSA rates the aggressivity as driver death rates in the struck vehicles. University of Oulu uses the driver relative injury risk in the opposite car, in relation to the risk of being injured in either of the two cars involved, as an estimation of aggressivity (Huttula 1997). The method used by Monash University Accident Research Centre (Cameron et al. 1997) combines injury risk and injury severity in the other vehicle when involved in a crash with the case vehicle.

Large differences in aggressivity have been shown regarding death rates in the USA (NHTSA 1999). The death rates ranged from a figure of 0.45 for the subcompact cars to 2.47 for the full-size vans. Large differences have also been found in the other studies mentioned.

None of the aggressivity rating methods separates the influence of mass and structure on aggressivity to the other vehicle. The objectives of this study was to present a method, based on the paired comparison technique, where mass and structural related aggressivity have been separated and to present differences in these aggressivity parameters for some different vehicle categories. The paired comparison technique was originally developed by Evans (1986), but has been further developed by Hägg et al. (1992) and Hägg et al. (2000).

METHODS

Relative Injury Risk Calculated with Paired Comparisons

The relation of injuries for two car models, car 1 and car 2, colliding with each other can be expressed as the number of injured in car 1 in relation to car 2. For a given segment *i*, where the impact severity can be considered to be constant, see Figure 1. The number of injured in both cars can be considered as products of the number of impacts in that segment (n_i) and the injury risks in that segment (p_{1i} and p_{2i}). This is further described by Hägg et al. (2000).

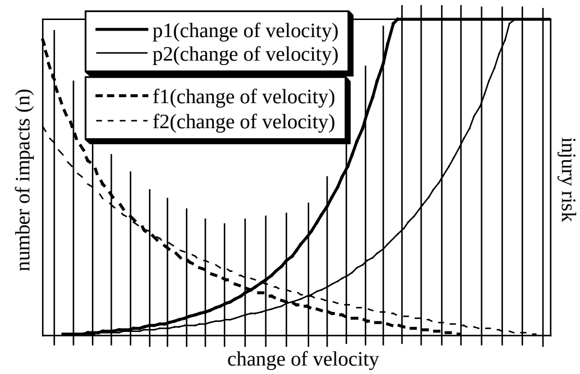

Figure 1. Injury risk (p_1 and p_2) and number of impacts (f_1 and f_2) for car 1 and car 2 versus change of velocity for segments of impact severity (from Hägg et al. 2000).

Assuming that the probabilities are independent, four cases can be summed; x_1, x_2, x_3 and x_4. These are explained in Table 1. The relative driver injury risk at a given crash severity in segment *i* is only calculated from three of the cells, where at least one driver has been injured. It can be seen that the relative injury risk in segment *i* is equal to;

$$R_i = (x_{1i} + x_{2i}) / (x_{1i} + x_{3i}) = \frac{n_i P_{1i} P_{2i} + n_i P_{1i} (1 - P_{2i})}{n_i P_{1i} P_{2i} + n_i (1 - P_{1i}) P_{2i}} = \frac{n_i P_{1i}}{n_i P_{2i}} \qquad \text{(Eq.1.)}$$

While Equation 1 shows that n_iP_{1i}/n_iP_{2i} is the estimate for the relative driver injury risk in one segment, the

Table 1.
Probability of Injury for Car 1 and Car 2

		Driver of Car 2		Total
		driver injured	driver not injured	
Driver of Car 1	driver injured	$\sum_{i=1}^{m} n_i P_{1i} P_{2i} = x_1$	$\sum_{i=1}^{m} n_i\ 1\text{-}P_{1i}\ (1\text{-}P_{2i}) = x_2$	$\sum_{i=1}^{m} n_i P_{1i} = x_1 + x_2$
	driver not injured	$\sum_{i=1}^{m} n_i (1\text{-}P_{1i}) P_{2i} = x_3$	$\sum_{i=1}^{m} n_i (1\text{-}P_{1i}) (1\text{-}P_{2i}) = x_4$	
	Total	$\sum_{i=1}^{m} n_i P_{2i} = x_1 + x_3$		

n_i = number of crashes in segment *i*
P_i = probability of injury in segment *i*
x_1= number of crashes with injured drivers in both cars
x_2= number of crashes with injured drivers in Car 1 and not in Car 2
x_3= number of crashes with injured drivers in Car 2 and not in Car 1
x_4= number of crashes without injured drivers in both car

sum over all segments is the estimate for all car-to-car crashes for a specific combination of cars. Table 1 shows the sum of the whole range of impact severity. Similarly, under the assumption that the injury risk in Car 2 can be expressed as the injury risk in Car 1 multiplied with a constant, the relative injury risk (R) in the whole range of impact severity is equal to:

$$R = (x_1 + x_2) / (x_1 + x_3)$$

$$= \sum_{i=1}^{m} n_i P_{1i} / \sum_{i=1}^{m} n_i P_{2i} \qquad \text{(Eq. 2.)}$$

Influence of Mass, Aggressivity and Impact Severity on the Relative Injury Risk

Some factors, apart from the design, may influence the relative injury risk for a car model. The following section will explain the influence of mass relations, aggressivity and impact severity on both injury risk and relative injury risk. To demonstrate the influence of these factors, three parameters can be introduced:

s = impact severity parameter
m = mass relation parameter
a = structural aggressivity parameter

The mass of a particular car model will have an influence on its relative injury risk in two-car crashes. The change of velocity for a car model will be lower than the change of velocity for its collision partner if its mass is higher than its collision partner. It will result in a benefit for the studied car and a disadvantage for the collision partner. The disadvantage for the other car can be regarded as the aggressivity due to the increased mass of the studied car.

In Figure 2 it can be seen that the number of impacts at a given change of velocity will be changed with a factor *m* for both cars, but in opposite directions. The aggressivity due to the structure of the studied car may influence the results as well. It is here defined as the influence on injury risk to the other vehicle, due to the structure of the studied vehicle, see Figure 2. It can be seen that the injury risk for Car 2 (p_2) is increased with the structural aggressivity factor *a* at all changes of velocity. If the studied car in average is colliding at higher speeds this will mean an increased average crash severity of the studied car in comparison to other vehicles. This increased severity could influence the individual injury risk *p* for both the studied car and its collision partners, but will not influence the relative injury risk because the change in severity will always be the same for both vehicles involved, as will be shown below.

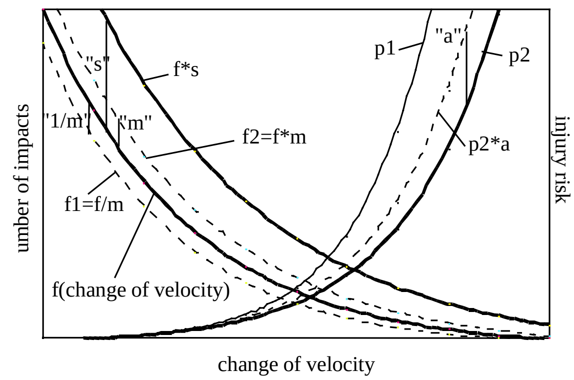

Figure 2. Influence of impact severity, mass and aggressivity on injury risk and number of impacts versus impact severity (change of velocity).

Table 2 shows the probabilities of injury from Table 1, including the three introduced parameters. The relative injury risk will with these parameters included be:

$$R = \sum_{i=1}^{m} (Np_1 s/m)) / \sum_{i=1}^{m} (Np_2 mas)$$

$$= \sum_{i=1}^{m} p_1/(p_2 a m^2) \qquad \text{(Eq. 3.)}$$

This means that the relative injury risk, as described in Equation (1) and (3), is influenced by mass relations and structural related aggressivity, but not influenced by crash severity. However, it should be noted that the individual injury risk for each car as well as for x_1, x_2 and x_3 are influenced by crash severity. Since the influence of crash severity on x_1 is squared compared to the influence on x_2 and x_3, the ratio $x_1/(x_2 + x_3)$ could be used as an indicator of the average crash severity for a particular car model. The ratio p_1/p_2 in Equation 3 is the design effect, which is the relative injury risk without influence of mass and structural related aggressivity.

Calculation of the Mass Factor (*m*)

The relation between the number of crashes with injured drivers in both vehicles and the number of crashes with injured drivers in the studied vehicle is a measure of the injury risk in the other vehicle. The relative injury risk in car 2, p_2, can be estimated as the relation $x_1/ (x_1 + x_2)$. Assuming that for every car 1 studied, its colliding partners, car 2, should be of equal design, mass and structure, p_2 should be identical in every case.

Table 2.
Probability of Injury for Car 1 and Car 2, Including Parameters for Impact Severity, Mass Relation and Structural Aggressivity

		Driver of Car 2		Total
		driver injured	driver not injured	
Driver of Car 1	driver injured	$\sum_{i=1}^{m}$ N ($p_1 s/m$) ($p_2 mas$) = $\sum_{i=1}^{m}$ $Np_1p_2as^2 = x_1$	$\sum_{i=1}^{m}$ N $p_1(s/m)$ $(1-p_2 mas)$ $= x_2$	$\sum_{i=1}^{m}$ N p_1 (s/m) $= x_1 + x_2$
	driver not injured	$\sum_{i=1}^{m}$ N $(1-p_1 s/m)$ $p_2 mas = x_3$		
	Total	$\sum_{i=1}^{m}$ N $p_2 mas = x_1 + x_3$		

The difference in the measured p_2 will differ depending on the influence of the three factors *m*, *a* and *s*. By selecting vehicles of different mass categories and where the structural aggressivity and impact severity factors could be regarded as equal it is possible to calculate the mass factor.

The cars were categorized in 100 kg intervals and the estimate of p_2, the ratio $x_1/(x_1 + x_2)$, was calculated for each comparison of mass categories. The relation between mass difference and the difference in estimate of p_2 was studied to calculate the influence of mass - the mass factor - as a function of the mass difference.

Control of Severity Factor, (*s*)

To be able to calculate the structural aggressivity factor, the severity factor has to be calculated or estimated. For most basic car models within the same vehicle category, not including the high performance versions, the crash severity could be regarded as equal, which means that the severity factor could be set as 1. However, when comparing vehicles in different vehicle categories, the severity could differ, probably most depending on whether the vehicle model mainly has been driven in suburban or urban areas. There are no direct measurements of the severity in the police data. To check whether the crash severity differ in the comparisons of the different vehicle categories, average speed limit for the crashes of each category has been used.

Calculation of Structural Aggressivity Factor, (*a*)

Similarly as in the calculation of the mass factor, the estimate of p_2, $x_1/(x_1 + x_2)$, was used to calculate the structural aggressivity factor. The differences in the measured ratio will differ depending on the influence of the three factors *m*, *a* and *s*. As p_2 should be equal for all car models, the difference between the average p_2 and the one for each vehicle category or model depends on the three factors. To be able to calculate the structural aggressivity factor both the mass factor and the severity factor must be known or estimated. With the mass factor calculated as explained above and the severity factor estimated based on the average speed limits, the aggressivity factor could be directly calculated as shown below.

$$a = (p_{2,\ measured} / p_{2,\ average})*(1/s)*(1/m) \qquad \text{(Eq. 4.)}$$

Calculation of Combined Mass and Structural Related Aggressivity

As both mass and structure will influence the total aggressivity of a car model, the combined aggressivity factor was calculated as the product of the mass factor, *m*, and the structural aggressivity factor, *a*, (Total aggressivity = *m***a*).

MATERIAL

This study was based on police reported car-to-car crashes containing at least one injured driver. Three different sub samples were used. In the study of differences between different vehicle size categories 13,292 crashes were used with car models introduced

1989 and later. In the study regarding year of introduction 52,480 crashes was used with car models introduced 1970 and later. Regarding the study of aggressivity for Euro NCAP star rated cars 9,302 crashes was used with car models introduced 1992 and later.

All collisions occurred between 1994-01-01 and 2000-12-31. In the collisions it was known if the occupants were injured or not. The police in the field have classified the injuries in correspondence with the ECE definitions. Four injury levels are used; no injury; minor injury; severe injury; and fatal injury. The severe injuries should typically lead to hospital admittance. Only injured drivers are studied.

Rating results from cars tested by Euro NCAP until 2000-12-31 was used in the study of aggressivity for car categories with different Euro NCAP stars.

The vehicles were categorised in size according to the method used in the Folksam car model safety ratings (Hägg et al. 2000). This categorisation is similar as the one used by Euro NCAP. The category SUV consists of both pickups and utility vehicles.

RESULTS

Figure 3 shows the relation between mass difference, here expressed in %, and mass factor for all combinations of mass differences studied. For example at 0% difference, four points can be seen. These relates to four combinations of cars; 1100 to 1100 kg, 1200 to 1200 kg, 1300 to 1300 kg and 1400 to 1400 kg.

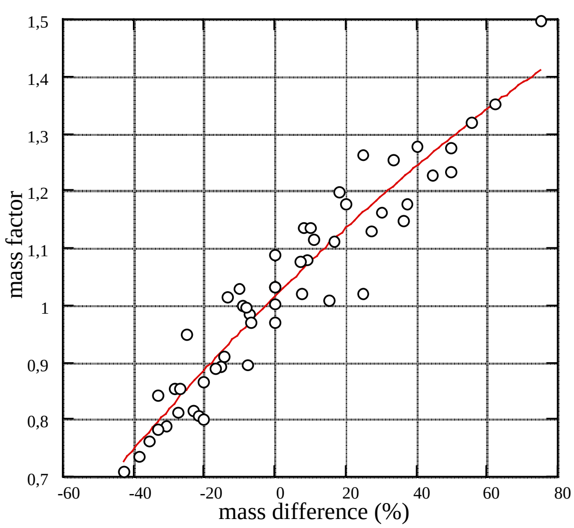

Figure 3. Relation between mass factor and mass difference.

A polynomial curve fit was found (R=0.96) with the equation;

$$m = 1 + 0,62*M_{diff} - 0,00122M_{diff}^2, \text{ where} \quad \text{(Eq. 3)}$$

$$M_{diff} = (mass_{case\ vehicle} - mass_{average\ vehicle})/mass_{average\ vehicle}$$

Relatively small differences in average speed limits for the different vehicle categories were found, see Table 3. Therefore the severity factors *s* were set to one in the calculation of the aggressivity factors *a*.

Table 3.
Average Speed Limits and Severity Factors for the Different Vehicle Categories

Vehicle class	Number of cases	Average speed limit	Relative difference
SUV	38	65.26	0,994
MPV	266	66.46	1,012
Large family vars	4129	65.63	0,999
Family cars	2625	66.10	1,007
Small family cars	3627	65.70	1,000
Small cars	961	64.26	0,979
Year of introduction			
1970-74	1809	65.90	1.004
1975-79	6397	65.99	1.005
1980-84	21374	65.63	0.999
1985-89	11081	65.55	0.998
1990-94	8540	65.56	0.998
1995-99	3095	65.96	1.004
Euro NCAP stars			
No class	3005	65.66	1.000
2 stars	3514	65.83	1.002
3 stars	1787	65.76	1.001
4 stars	1009	65.62	0.999
Average		65.67	1.000

Table 4, 5 and 6 present the total number of crashes and the number of crashes with different combinations of injured drivers for the different categories of vehicles studied.

Table 4.
Number of Crashes with Different Injury Combinations for Different Vehicle Categories

Vehicle class	Number	x_1	x_2	x_3
SUV	59	13	3	34
MPV	294	85	44	115
Large family cars	4121	1087	946	1369
Family cars	3563	960	955	1079
Small family cars	4091	1186	1274	999
Small cars	1164	347	440	229
Total	13,292	3,678	3,662	3,825

Table 5.
Number of Crashes with Different Injury Combinations for Cars with Different Years of Introduction

Year of introduction	Number	x_1	x_2	x_3
1970-74	1809	492	511	535
1975-79	6397	1733	1988	1671
1980-84	21374	5698	6156	6063
1985-89	11081	2916	3258	3060
1990-94	8540	2324	2301	2485
1995-99	3082	908	829	903
Total	52480	14120	15110	14761

Table 6.
Number of Crashes with Different Injury Combinations for Cars with Different Euro NCAP Star Rating

Euro NCAP stars	Number	x_1	x_2	x_3
No class	3005	854	859	829
2 stars	3514	989	1026	954
3 stars	1779	504	442	550
4 stars	1004	310	279	271
Total	9302	2657	2606	2604

The SUVs were found to have 32% higher mass factor and 23% higher structural aggressivity factor than that of the average car, see Table 7. This results in a 62% higher total aggressivity factor than average. The MPVs were found only to have 3% higher structural aggressivity factor than average, while the mass factor was 28% higher than average, resulting in 32% higher total aggressivity factor than average. It was also found that small cars had higher structural aggressivity factor than the family car categories, while the mass factor was smaller. Due to the lower mass factor of the small cars, the total aggressivity factor was found to be 18% higher for the large family cars compared to the small cars, see Table 7.

Only small differences in the structural aggressivity factor was found for cars with different year of introduction, while an increase in the mass factor of approximately 10% between 1970 and 1995 was found, see Table 8.

Cars with 4 stars in Euro NCAP was found to have 5% higher structural aggressivity factor than cars with 2 and 3 stars, see Table 9. However, the 3 star rated cars were found to have 8% higher mass factor than the 2 star cars, resulting in 5% higher total aggressivity than average.

Table 7.
Mass, Structural Aggressivity and Total Aggressivity Factors for Different Vehicle Categories

Vehicle category	average mass	*m*	*a*	***m****a*
SUVs	1916	1.32	1.23	1.62
MPVs	1827	1.28	1.03	1.32
Large family cars	1532	1.13	0.94	1.07
Family cars	1363	1.05	0.95	1.00
Small family cars	1175	0.96	1.00	0.96
Small cars	985	0.86	1.02	0.88
Total	1337	1.00	1.00	1.00

Table 8.
Mass, Structural Aggressivity and Total Aggressivity Factors for Cars with Different Years of Introduction

Year of introduction	average mass	*m*	*a*	***m****a*
1970-74	1199	0.97	1.05	1.02
1975-79	1174	0.96	1.01	0.96
1980-84	1215	0.98	1.02	1.00
1985-89	1239	0.99	0.99	0.98
1990-94	1344	1.04	1.00	1.04
1995-99	1376	1.06	1.00	1.08
Total	1240	1.00	1.00	1.00

Table 9.
Mass, Structural Aggressivity and Total Aggressivity Factors for Cars with Different Euro NCAP star rating

Euro NCAP stars	average mass	*m*	*a*	***m****a*
No class	1254	1.00	0.99	0.99
2 stars	1258	1.00	0.97	0.97
3 stars	1427	1.08	0.98	1.05
4 stars	1310	1.02	1.02	1.04
Total	1295	1.00	1.00	1.00

DISCUSSION

The definition of aggressivity is not evident and several different definitions are being used. In this study it is defined as the influence on injury risk to the other vehicle, due to the design of the studied vehicle. These design parameters were separated into mass and structure of the studied vehicle. In most studies the combined influence of these parameters is analyzed. Both parameters seem to be important to have in mind in the design of compatible vehicles.

In this study it was assumed that the injury risk in one car model could be expressed as the injury risk in another car model multiplied with a constant. This assumption is probably valid at most crash severities. However, at high crash severity, where the injury risk approaches one, this is not valid. This fact could slightly influence the results found if the average crash severity for a car category was very high. This is, however, probably not likely regarding the vehicle categories in this study, which was also shown by the small differences in average speed limits.

As the variation in speed limits were small, the variation in crash severity was estimated to be small for the different vehicle categories. The influence on the calculated aggressivity factors will by that be very small. Therefore, the severity factors were set as 1.00 in the calculation of the structural related aggressivity factors. The correct aggressivity factors are slightly smaller than the estimated factors for cars with higher crash severity than average and vice versa.

A factor that could influence the results apart from the mentioned factors mass, severity and structural aggressivity, is seatbelt use. A low seatbelt use in a vehicle or vehicle group will have the effect that the injury risk will be higher than the correct value. When calculating relative injury risk, this will have the effect that the injury risk in the car it collides with will be lower than what is correct, which in turn will have the effect that these vehicles will tend to be less aggressive than they actually are. In the vehicle categories studied, introduced 1989 and later, the belt usage rate is probably very similar. However, when comparing vehicles introduced at different years and colliding 1994 and later, cars introduced in the 70's would probably have a lower seatbelt use than cars introduced in the 90's. This will have the effect that cars introduced in the 70's appear to be less aggressive that they actually are.

The number of crashes with MPVs and especially SUVs was small, which makes the significance of the differences in aggressivity found for these vehicle categories low. Further studies with more data, especially for the SUVs, are necessary to conduct.

An interesting finding was that cars introduced in the early 70's not were found to have higher structural aggressivity factor than cars introduced in the 90's. Since the structure consists of several factors, such as stiffness and homogeneity of the front-end structure, stiffer cars with better homogeneity could be less aggressive than less stiff cars with worse homogeneity. This could be the fact when comparing car models from the 70's with cars from the 90's.

With more data it could also be possible to study mass and structural related aggressivity for vehicle categories introduced at different years. Different developments in structure could be expected for the various vehicle categories.

SUVs were in this study, when rating the risk of any injury, found to be approximately 85% more aggressive than the small cars. In the study from NHTSA (NHTSA 1999) regarding death rates, SUVs were found to be more than 4 times more aggressive than the subcompact cars. The more severe injuries that are studied, the larger differences in aggressivity and risk can be expected. Again, it should be noted that the number of crashes with SUVs was relatively small in this study. Further studies with more crashes are necessary to get more reliable results.

The grouping of cars into Euro NCAP star groups shows that there are only small differences between cars in different groups. This finding indicates that good performers in Euro NCAP tests do not cause more risk to opponent cars under real life conditions.

The findings in this study are also important to take into consideration in car model safety ratings using the paired comparison technique. Both mass and structural related aggressivity influence the relative injury risk. However, as the influence of mass and structure could be separated, it is possible to compensate for their influences on relative injury risk separately. Influence of mass could directly be adjusted for as the mass factor can be directly calculated. The structural related aggressivity factor is more difficult to handle, as the crash severity factor has to be known or estimated for the car models or categories studied. For many car models the crash severity could probably be estimated as equal. However, when comparing vehicle categories with high structural aggressivity factor, such as SUVs, with passenger cars such assumption is not valid as shown in this study. On the other hand, MPVs was found to have a structural aggressivity factor similar to those of the family car categories, indicating that rating results from MPVs could be compared with rating results from the family car categories with only small errors if aggressivity is not adjusted for.

Another finding was the average structural related aggressivity factor was found to be less than the mass factor for all vehicle categories, indicating that the influence of mass is more important to take into consideration in car model safety ratings than the structural related aggressivity.

CONCLUSIONS

- SUVs were found to have 32% higher mass factor and 23% higher structural aggressivity factor than the average car, resulting in a 62% higher total aggressivity factor than the average.
- MPVs were found to have 3% higher structural aggressivity factor than average, while the mass factor was 28% higher than average, resulting in 32% higher total aggressivity factor than average.
- It was also found that small cars had higher structural aggressivity factor than the family car categories, while the mass factor was smaller. Due to the lower mass factor of the small cars, the total aggressivity was found to be 17% higher for the large family cars compared to the small cars.
- Only small differences in the structural aggressivity factor was found for cars with different year of introduction, while an increase in the mass factor of approximately 10% between 1970 and 1995 was found.
- Cars with 4 stars in Euro NCAP were found to have 5% higher structural aggressivity factor than cars with 2 and 3 stars. However, the 3 star rated cars were found to have 8% higher mass factor than the 2 star cars, resulting in 5% higher total aggressivity than average.

REFERENCES

Buzeman-Jewkes D. Car Compatibility in Frontal Crashes: New Methods to Determine the Influence of Mass, Structure, Stiffness, and Geometry, and their Interaction on Injuries. Thesis for the dregree of Doctor in Philosophy, Chalmers University of Technology, Göteborg, 1998.

Cameron M, Newstead S, Les M. Rating the Aggressivity of Australian Passenger Vehicles Towards Other Vehicle Occupants and Unprotected Road Users, Proc. of the Int. IRCOBI Conf. on the Biomechanics of Impacts, Göteborg, Sweden, 1998.

Huttula J, Pirtala P, Ernvall T. Car Safety, Aggressivity and Accident Involvement Rates by Car Model, University of Oulu, ISBN 951-42-4865-5, 1997.

Hägg A, v Koch M, Kullgren A, Lie A, Nygren Å, Tingvall C, Folksam Car Model Safety Rating 1991-92, Folksam Research 106 60, Stockholm, Sweden, 1992.

Hägg A, Krafft M, Kullgren A, Lie A, Malm S, Tingvall C, Ydenius A. Folksam Car Model Safety Ratings 1999, Folksam Research, 10660 Stockholm, Sweden, 2000.

Evans L. Double Pair Comparison – a New Method to Determine how Occupant Characteristics Affect Fatality Risk in Traffic Crashes. *Accid. Anal. and Prev*., Vol. 18, No. 3, 1986. pp 217-227.

IIHS. Status report, Vol. 34, No. 9, October 30, 1999. (see www.hwysafety.org)

Lie A, Tingvall C. How Does Euro NCAP Results Correlate to Real-life Injury Risk – A Paired Comparison Study of Car-to-Car Crashes. Proc. of the Int. IRCOBI Conf. on the Biomechanics of Impacts, Montpellier, 2000.

Parker B, Hackney J, Morgan R, Chan H. The New Car Assessment Program: Has it Led to Stiffer Light Trucks and Vans Over the Years? SAE Int. Congress and Exposition, Detroit, MI, USA, 1999.

Wykes N, Edwards M, Hobbs A. Compatibility Requirements for Cars in Frontal and Side Impact. Proc. of the 16th Int. ESV Conf., Paper No. 98-S3-O04, Windsor, Canada, 1998.

Zobel R. Demands for Compatibility of Passenger Vehicles. Proc. of the 16th Int. Technical Conf. On the Enhanced Safety of Vehicles (ESV), Windsor, Canada, 1998.