Car model safety rating using paired comparisons.

Krafft M, Nygren C, Tingvall C. Chalmers University of Technology, dep of Injury Prevention, Göteborg and Folksam research and development, Stockholm.

ABSTRACT

Several ways of collecting data, calculation and presentation of data has been developed aimed at rating the interior safety of different car models. One of the most difficult parts has been to estimate the crash severity which can vary considerably between different car models and thereby influence the relative safety.

In this paper a method and some results are presented using paired comparisons which is a technique developed in order to control accident severity without collecting data about accident severity itself but instead using some simple assumptions about two-car accidents.

Three different car models are compared and rated relative to each other. The influence of weight is also demonstrated by using the method.

Background

Rating the safety of constructions or whole cars is an important issue in the traffic safety field for the purpose of the work of legislators, manufacteurs and information to the public. New concepts, safety devices, trends and car models must be followed up in order to get feed back in the continuous work of improving safety.

Concerning rating of car models, there are four major systems available. NHTSA every year conducts barrier tests in 35 mph with instrumented dummies. The results are published in different ways, and it seems to be partly used as a rating systems for different car models (1, 2).

The Insurance Institute of Highway Safety publishes results from Highway Loss Data Institute where claims results from different insurance companies are aggregated and computated (3).

Vehicle Safety Consultants conducts thoroughful inspections of new cars that is published in the U.K. magazine "Which" (4).

Folksam Insurance company in Sweden publishes results from data collection made in connection with claims reported to the company and data from the National Bureau of Statistics in Sweden (5).

There are several problems associated with analyzing results for the purpose of rating cars. In materials not based on accidents there is a problem validating the results from e.g. barrier tests, while in materials based on real life accidents, the problem with standardizing accidents with respect to type and severity seems to be the most dificult one (6).

Rating systems based on real life accidents must contain many accidents in order to get a reasonable precision for many car models. It is therefore complicated to get measurements to be used to calculate accident severity. It can also be complicated to have a fairly good estimation on the accident exposure.

In this paper a method aimed at diminishing the problem with lacking data on accident severity and exposure is presented. The method is based on the work of Evans on double paired comparisons (7, 8).

Method

The fundamental problem can be described with probability distribution functions. In Fig. 1 two hypotetical curves showing the risk of injury linked to accident severity for two different car models is showed. One car is better than the other in that the distribution is shifted to the right, that is for a given accident severity, the probability of injury is lower.

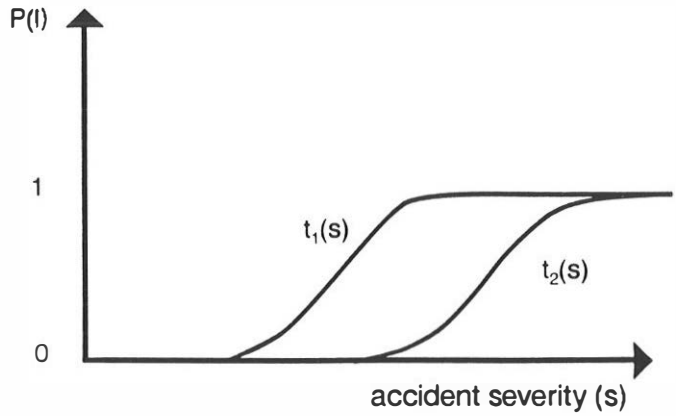

Fig. 1. Schematic probability functions for injury risk for different accident severity. $t_1(s)$ refers to car 1 and $t_2(s)$ to car 2.

In Fig. 2. two accident severity distributions for two car models is showed. The distributions are hypotetical. Car (2) is involved relatively more frequently in severe collisions compared to car (1).

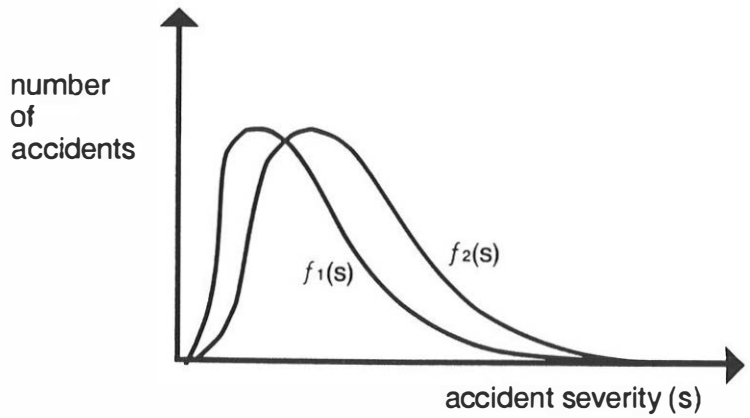

Fig. 2. Schematic distribution of accidents of different accident severity. $f_1(s)$ refers to car 1 and $f_2(s)$ to car 2.

The accident severity distribution is, however, unknown for different car models. This would not create any problem if all accident severity distributions for different cars were identical. This seems however to be a to optimistic assumption. There is though one situation where this is true and that is when the two different car models collide with each other (given a mass relation of 1:1).
According to Evans (7), the relation of injuries for car 1 and 2 given the same accident severity distribution is:
where:
d = the number of injured in car 1 = $N\int t_1(s)f(s)ds$
e = the number of injured in car 2 = $N\int t_2(s)f(s)ds$
N = total number of accidents
For a given segment m where the accident severity can be considered to be constant (Fig. 3) d and e can be considered to be products of two probabilities; p_1 and p_2, where p_1 is the risk to be injured in car 1 for a given severity and p_2 the corresponding probability in car 2.

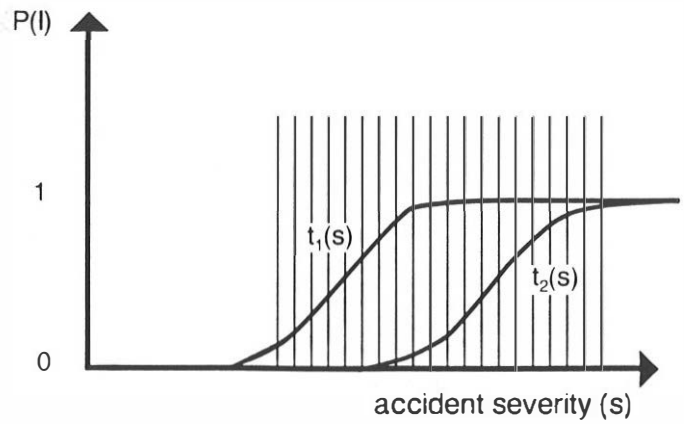

Fig. 3. Segmented probability functions for injury risk for different accident severity for car 1 $t_1(s)$ and car 2 $t_2(s)$.

		Car 2	
		injured in	not injured in
Car 1	injured in	$N \cdot p_1 \cdot p_2 = x_1$	$N \cdot p_1 \cdot (1 - p_2) = x_2$
	not injured in	$N \cdot (1 - p_1) \cdot p_2 = x_3$	$N \cdot (1 - p_1) \cdot (1 - p_2) = x_4$

Table 1. Probabilities of injury in car 1 and 2 in a given segment of accident severity.
In table 1 the probabilities are separated. The probabilities are assumed to be independent for all given segments where the accident severity and probabilities of injury respectively can be considered as constant. It can be seen that the ratio d/e in this segment is equal to the ratio

$$R = x_1+x_2/x_2+x_3 \text{ (where } d=x_1+x_2 \text{ and } e=x_1+x_3)$$

which is the same as;

$$R = p_1/p_2 \quad \left[\frac{p_1 \cdot p_2 + p_1 \cdot (1 - p_2)}{p_1 \cdot p_2 + p_2 \cdot (1 - p_1)} \right]$$

Both p_1 and p_2 can be calculated through x_1, x_2 and x_3. p_1 can be calculated by:

$$p_1^* = \frac{x_1/x_3}{(1 + x_1/x_3)}$$

And p_2 by:

$$p_2^* = \frac{x_1/x_2}{(1 + x_1/x_2)}$$

It is easy to show that if p_1/p_2 is the estimator for a given segment, it is also true for the whole range of accident severity. Identical formulas are therefore used for all accidents together.
The same assumptions and theory is used for estimating the variance of the estimates p_1/p_2, p_1 and p_2. By using Cochran's theorem for subdivision of variances, it can be seen that the variance could be calculated from the estimates of p_1 and p_2. By using Gauss approximation for the variance of ratios, the variance is calculated by;

$$\hat{V}(R) = \frac{p_1^*}{p_2^*}\left[\frac{(1-p_1^*)}{(x_1+x_2)} + \frac{(1-p_2^*)}{(x_1+x_3)}\right]$$

It can be understood from he formulas that the method as described above cannot be used on a true accident material, as the number of combined accidents for different cars will be to few. Instead, the opposite car (ie car 2) will be all cars that were involved in accidents (with car 1). Thereby, it must be assumed that the distribution of all opposite cars is similar for all investigated car models, or can be normalized. If so, the opposite cars must be known concerning make, model and weight.
It is also obvious that there must be a possibility to compensate for other mass relation than 1:1 as the opposite car can gain from a low weight car and vice versa.

Material

The material used to show how the described method works was collected by the police and reported to the National Bureau of Statistics. Only combined accidents with private cars were used. All cars were identified by the registration number giving the car model and specification. The accidents occured during 1985 and 1986. Only drivers were included. The injuries were classified in three groups; fatal, serious and slight. In this paper the injuries were not subdivided according to severity.
The weight of the car was judged according to the swedish specification of the car which is the car and a driver weighing 75 kg.

Results

In table 2, the ratios and separate p-values for cars of different weights colliding with all other cars are shown. It can be seen that there is a strong trend in that the ratio decreases with increasing weight for the specific car weight. It can also be seen that the p-value for the opposite cars (p_2) increases with increasing weight. This effect, which is not desired, is taken care of by normalizing for weight. In average, the estimated p_2 value increases with 0.03 for every 100 kg extra service-weight for the specific car. By subtracting 0.03 from the p_2 value a modified ratio R can be calculated. The modified ratio is also shown in table 2.
Table 2. Ratio R (p_1/p_2) and separate p_1 and p_2 for cars of different weights and their opposite cars in two car collisions. R' refers to modified ratio R corrected for weight.

Service weight	R	p_1	p_2	R'
800	2.23	0.63	0.28	1.70
900	1.67	0.55	0.33	1.41
1000	1.47	0.54	0.37	1.35
1100	1.25	0.46	0.37	1.25
1200	0.91	0.41	0.46	0.95
1300	0.84	0.36	0.43	0.84
1400	0.78	0.38	0.48	0.97
1500	0.64	0.32	0.50	0.84

It can also be seen from table 2, that the influence of weight on the injury risk in the specific car is strong. Looking at the modified ratios, the risk of injury is doubled in small cars (800 kg) compared to large cars (1300 kg or more).

In table 3, the number of accidents with Volvo 740 were subdivided according to if the driver in the Volvo, in the opposite car, or in both were injured. The estimates of injury risks p_1, p_2 and p_1/p_2 were calculated according to the formulas above. In table 4, the corresponding figures for Saab 900 are shown.

Table 3. The number of drivers injured in Volvo 740 and cars colliding with Volvo 740 (x_1), the number injured in Volvo 740 but not into opposite car (x_2) and vice versa (x_3). R and R' refers to risk ratios. p_1 and p_2 refers to individual estimated injury risks in Volvo 740 (p_1) and opposite cars (p_2).

$x_1 = 30$	$x_2 = 31$	$x_3 = 66$
$R = 0.64$	$R' = 0.72$	
$p_1 = 0.31$	$p_2 = 0.49$	

Table 4. See table 3 except that the specific car is Saab 900.

$x_1 = 53$	$x_2 = 81$	$x_3 = 114$
$R = 0.80$	$R' = 0.87$	
$p_1 = 0.32$	$p_2 = 0.40$	

The modified ratio R was corrected for weight by subtracting the p_2 value for Volvo 740 by 0.06 (2 timers 0.03) and 0.03 for Saab 900. The average weight of the cars are 1300 kg for the Volvo and 1200 kg for the Saab.

It can be seen from tables 3 and 4 that the Volvo 740 generates more injuries in the opposite car compared to the Saab 900, even when corrected for weight. According to the previous assumptions, this would indicate that the accident severity is higher when a Volvo is involved in an accident compared to a Saab 900.

Discussion

Rating cars and car constructions on the basis of real world accidents and quantitative analysis is a complicated problem. The most complicated part is normally to handle exposure both in terms of how many accidents a certain car is involved in as well as how severe these accidents were. Both these factors are strongly correlated to the number of injured and must therefore be controlled for.

In the technique presented in this paper, both problems are taken care of. It is not necessary to know how a certain car model is exposed to accidents or how many accidents a car is involved in. There is also no need to know how severe the accidents were. The data that must be available for the analysis is only injury producing accident data.

There are of course limitations in the method in that only combined accidents are rated. Single accidents are left outside the method.

There are also some assumptions made, that must be investigated further. In the method described, the outcome in the opposite vehicle is one of the two basic parametres, and it is assumed that the outcome is only due to mass relation and accident severity where the accident severity is dependent on some velocity factor. If there is also a factor related to the aggressiveness of a certain car model, this is outside the model. It seems however that this could be investigated with a sufficiently large material.

The method is probably also sensitive to biased materials ie if only one of the drivers is injured while both were, and if this tendency is linked to injury severity. It is also true, that the material must be large, as the precision in the estimates is not only due to the injury proportion in the specific car model, but also the opposite car.

Bias can also be introduced if there are large differences in age and sex distributions among drivers of different cars. Evans (8) has showed there is a strong and consistent correlation between age and risk of fatality that can also be adressed to risk of injury. Indirectly, age can also play an important role in that the use of safety devices such as seat belts could be linked to age. It is therefore of importance to study if age and other relevant factors are distributed in a way that they cannot affect the result or otherwise to control for these factors.

One basic assumption is that different accident severity distributions should not affect the ratio if a car relatively to another is equal. This assumption has to be validated further.

It seems sometimes to be necessary to have the estimate of accident severity for an individual or a set of individual accidents. In studies aimed at linking accident outcome and severity (9) it is not possible to use the method presented in this paper directly. By combining materials with accidents severity calculated on an individual basis with this method, it seems however that use of the method can be extended.

The injury severity is not included in the method, but there does not seem to be any factor that would make impossible to use data where this is available. It is also possible to study specific injuries as well as specific safety devices. In the latter case, it seems to be of great importance that the exposure for a certain safety device do not have to be known a priori but can be taken from the accidents itself.

It would be of great interest to validate different rating systems to each other. It is therefore proposed that this method is included in such a comparison.

- Conclusions.
- By assuming that there is a relationship between accident severity and the injury outcome in an opposite vehicle, it is possible to rate the relative safety of a specific car or car construction.
- This assumption makes it unnecessary to collect any external data about exposure as well as data about accident severity.

References

1. Status report. IIHS Vol 23, no 9. 1988.
2. Gillis J. The car book. Harper and Row publications. New York. 1987.
3. HLDI injury and collision loss experience. IIHS. Washington D.C. 1988.
4. Which? Car buying guide 1988. London June 1988. (Gloyns P, Rattenbury S).
5. Gustafsson H, Hägg A, Krafft M, Malmstedt B, Nygren Å, Nygren C, Tingvall C. The sum of 700.000 car accidents. Folksam, Stockholm 1987.
6. Thomas C, Koltchakian S, Tarriere C. Inadequacy of 0 degree barrier with frontal real-world accidents. In: ESV Conference 1989. Paper no. 89-2A-0-002.
7. 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 pp. 217-227. 1986.
8. Evans L. Risk of fatality from physical trauma versus sex and age. The Journal of Trauma. Vol 28, no. 3 pp 368-378. 1988.
9. Korner J. A method for evaluating occupant protection by correlating accident data with laboratory test data. SAE technical paper series. Detroit 1989.