VEHICLE PROPERTIES DETERMINING AGGRESSIVITY

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Abstract

The objective of this study was to attempt to empirically quantify the effect various measurable physical vehicle properties have on aggressivity. Expert opinion and literature review was used to select for measurement the vehicle characteristics most likely to affect aggressivity. They included, amongst others, such characteristics as vehicle mass and frontal stiffness, dimensional properties such as bonnet height and length and the placement of key mechanical components relative to the external surfaces of the vehicle. Data on physical vehicle properties by field measurement were collected for 73 distinct makes and models of vehicles for which a vehicle aggressivity index had been estimated.

As a preliminary analysis, multiple regression analysis was applied to identify those measured physically vehicle properties that were associated with the estimated vehicle aggressivity index. Marketing grouping of vehicles (small, medium, large, luxury and 4WDs) allowed the comparative analysis with 4WDs included and excluded from the sample data.

The results showed a high association between vehicle wheelbase, bonnet leading edge height and bonnet length and the vehicle aggressivity index for the whole fleet. Repeating the analysis with 4WDs excluded from the sample data revealed vehicle wheelbase was the only factor showing the high level of association with the vehicle aggressivity index.

Keywords: vehicle aggressivity, occupant protection, vehicle property, compatibility

INTRODUCTION

Issues of vehicle compatibility, and the associated concept of vehicle aggressivity, have come to the fore as important in vehicle safety research in recent years. Aggressivity has been defined in different terms by different authors. One definition of the term "aggressivity" (Fildes et al. 1993) is the extent to which a vehicle transfers collision energy to the struck object in preference to absorbing the collision energy itself. Another definition of aggressivity used by Newstead et al. (2000) when related to injury outcome, is the fatality or injury risk to occupants of a vehicle colliding with the subject vehicle.

Large differences in aggressivity, as measured by death rates in the struck vehicle, have been shown between non-airbag vehicle classes in the USA (Joksch, 1998). The death rates ranged from a figure of 0.45 for occupants of vehicle struck by sub-compact cars, to 2.47 for occupants of vehicle struck by full-size vans.

Geometry, mass and stiffness are considered to be the three most important vehicle properties influencing aggressivity (see, for example, Gabler et al. 1998, Les et al. 1999). The relative influence of each of these factors is still uncertain. Each of these three factors can be characterized by a number of measures. In order to find which vehicle properties determine the aggressivity of a vehicle, tests with certain constant have been performed in several side-impact investigations (Nolan et al. 1999, Seyer et al. 2000, Wykes et al. 1998). However, according to (Digges and Eigen, 2001), the measurement of stiffness and geometric compatibility needs further definition.

Sports Utility Vehicles (SUVs) were found to be approximately 85% more aggressive than small cars in a study which rated the risk of injury (Kullgren et al, 2001). Another finding was that 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 in car model safety ratings than the structural related aggressivity.

The significance of parameters influencing aggressivity may be different depending on impact type. Seyer et al., (2000) state that in side impacts, the injuries become more severe with increasing front rail height in the bullet vehicle. In a study by Buzeman-Jewkes (1998) it was found that stiffness had the largest influence on injury in frontal offset impacts between cars, followed by bumper level and mass.

During the last decade several methods of vehicle aggressivity rating were developed and applied in different countries.

Vehicle Aggressivity Rating Methods

The following vehicle aggressivity rating methods have been developed by the international organizations:

- ?? The TRL method (Broughton 1994, 1996)

- ?? The Oulu method (Tapio et al. 1995, and Huttula et al. 1997)

- ?? The MUARC method (Cameron et al. 1998, Newstead et al. 2000)

- ?? The MLF method (Les et al. 2001)

- ?? The MUARC2 method (Les et al. 2001)

- ?? The MUARC3 method (Newstead 2001).

Review of vehicle aggressivity rating systems and their mathematical considerations and theoretical evaluation can be found in Les and Fildes (2000, 2001) and Cameron et al. (2001).

The vehicle aggressivity rating index applied in this study was developed using the MUARC method. It was assumed that in two-car crashes the estimated risk of driver injury in the *other* vehicle is a measure of the *subject* vehicle's aggressivity. The MUARC aggressivity rating is calculated in two steps: (1) other driver injury risk criterion, multiplied by (2) injury severity of the other driver. Injury severity is measured by the proportion of injured other drivers who were killed or severely injured (Newstead et al. 2000).

Although there are well developed statistical techniques applied for measuring vehicle aggressivity (e.g. logistic regression) there is no technique developed to measure relationship between vehicle aggressivity ratings and physical properties of the vehicle. In this preliminary analysis, multiple linear regression analysis was applied to identify those measured physically vehicle properties that were assumed to affect vehicle aggressivity. This analysis is considered as a preliminary one and, in further research, the used of non-linear statistical methods are planned.

METHOD

Data Collection

The Monash University Accident Research Centre has funded study on aggressivity of Australian passenger cars and 4WDs undertaken by Swedish students (Petterson and Holmqvist, 2001). Expert opinion and literature review were used to select the vehicle characteristics for measurement most likely to affect aggressivity. They included, amongst others, such characteristics as vehicle mass and frontal stiffness and dimensional properties such as bonnet height and length and placement of key mechanical components relative to the external surfaces of the vehicle. As a result, the vehicle database was set up that contained information on 73 distinct makes and models of vehicles sold in Australian, the aggressivity of which have been rated by Newstead et al. (2000). All vehicles were also grouped by the market grouping criteria: small, medium, large, luxury and 4WDs. This allowed the comparative analysis with 4WDs included and excluded from the sample data.

Statistical Method

As a preliminary analysis of the data, multiple linear regression technique was applied to identify those measured physically vehicle properties that best predicted the estimated vehicle aggressivity index.

The multiple linear regression model is of the form (Myers 1990):

$$Y ? ?_0 ? ?_1 X_1 ? ?_2 X_2 ? \ldots ? ?_n X_n ? \ldots ? ?_k X_k ? ?$$

where Y is the measured response variable (vehicle aggressivity), $?_n$ are model parameters to be estimated, X_n are the regressor variables (vehicle physical properties) and $?$ is the model error. Estimates of the parameter coefficients of the linear function, the $\hat{?}_i$, are obtained by the least squares procedure.

In this exploratory analysis, the main effects model was tested (with no interaction effects) to study the importance of the particular physical properties of the vehicle in predicting vehicle aggressivity. A stepwise procedure was used to identify those factors. In further analysis it is planned to add interaction terms to the model to study the joint effect of two regressor variables (vehicle physical properties) on vehicle aggressivity. A non-linear model will be also tested.

ANALYSIS

Information on seventy three vehicles inspected over the years 2000 and 2001 was included in the vehicle database. However, the aggressivity index values were available only for cars manufactured not later than 1998. As a result, only 51 cars were included in the final analysis.

It was of major importance to establish which physical properties of the vehicle contribute most to vehicle aggressivity. In this section the relationship between the vehicle aggressivity index and physical properties of the vehicle such as vehicle width, vehicle mass, frontal bonnet height etc. is described.

The first objective was to investigate any relationship between a single physical property of the vehicle and the vehicle aggressivity index. For this purpose the correlation analysis was used.

The second objective was to evaluate the combined effect of vehicle physical properties on aggressivity. For this purpose the multiple linear regression analysis was applied.

The relationship between the vehicle aggressivity ratings and year of vehicle manufacture was also investigated.

Relationship between aggressivity rating and physical properties of a vehicle

The results of correlation analysis between a single physical property of the vehicle and the vehicle aggressivity index can be found in Pettersson et al. (2001).

Multiple linear regression analysis was applied to identify those measured physically vehicle properties that best predicted the estimated vehicle aggressivity index. As it was assumed that passenger cars and 4WDs differ significantly in terms of size, it was of interest to test if they differ in terms of vehicle physical properties that are most likely to contribute to vehicle aggressivity. As a result two multiple regression models were fitted to the data, one to the data containing all vehicles, and the second one to the data with excluded 4WDs.

The multiple regression model fitted to the data containing all vehicles (with 4WDs):

$$AGGR = -8.4 + 0.023*WHEELB + 0.044*FBONHGT + 0.018*BONLGT$$

where AGGR – the vehicle aggressivity index, WHEELB –wheelbase, FBONHGT - frontal bonnet height, and BONLGT - bonnet length.

The standard errors of the constant and coefficients were 1.35, 0.007, 0.009 and 0.008 respectively. The value of R^2 was 64.9 or 62.3% if adjusted. The effect of wheelbase, frontal bonnet height and frontal bonnet length were statistically significant ($p < 0.05$) and all the coefficients have the expected sign. That is, the increase in size of vehicle physical properties is expected to increase the value of the vehicle aggressivity index.

The multiple regression model fitted to the data with 4WDs excluded from the analysis:

$$AGGR = -5.18 + 0.029*WHEELB$$

where acronyms have meanings as described above.

The standard errors of the constant and coefficient were 1.15 and 0.004 respectively. The value of R^2 was 54.1 or 52.9% if adjusted. In the cases when 4WDs were excluded from analysis, only the effect of wheelbase was found statistically significant ($p < 0.05$).

Are newer cars more aggressive?

There has been concern raised that new cars have stiffer frontal structure increasing vehicle crashworthiness but at the same time increasing vehicle aggressivity that can results in higher injury severity in the struck cars in the case of car-to-car crashes (Fildes et al. 2000).

Recorded in the vehicle database information on year of car manufacture allowed testing the change in average vehicle aggressivity over time. The Pearson's correlation between the vehicle aggressivity

index and year of vehicle manufacture was found to be 0.436 (significant at the p<0.01 level) indicating the existence of the relationship between the two (see Fig. 1).
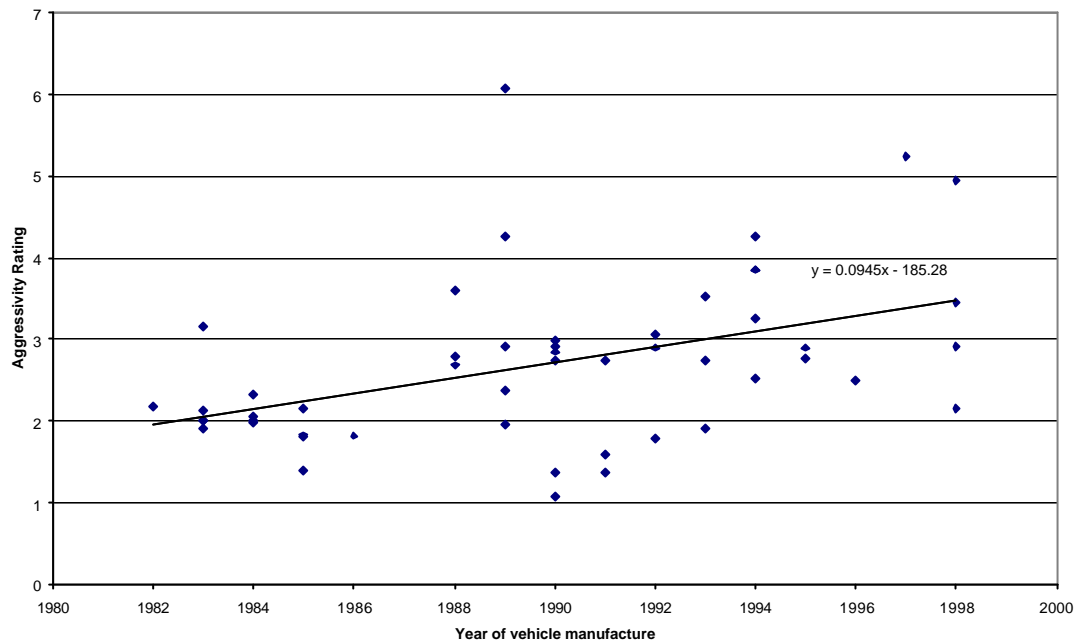

Figure 1. The relationship between vehicle aggressivity ratings and year of vehicle manufacture

Figure 1 shows that for some years there is a wider distribution of the vehicle aggressivity index values than for the others. Larger data sample is needed to test if the observed increasing linear trend in vehicle aggressivity over time is characteristic for the studied sample only or can be generalized for the whole vehicle fleet.

DISCUSSION

The exploratory data analysis was applied to identify the physical features of the vehicle contributing most to vehicle aggressivity. This would allow the development of strategies for the reduction of vehicle aggressivity.

It was found that in the cases of all vehicles (4WDs included in the analysis) there was a significant relationship between the vehicle aggressivity index and the explanatory variables: wheelbase, frontal bonnet height and frontal bonnet length. The effects of wheelbase, frontal bonnet height and frontal bonnet length were statistically significant despite the relatively small sample size.

It was of interest to assign relative importance to each physical feature of the vehicle identified by the statistical model. It was important to know whether there is one factor that is more important in terms of contribution to vehicle aggressivity than other factors. The following questions were raised:

?? How important are wheelbase, frontal bonnet height and frontal bonnet length when each one is used alone to predict vehicle aggressivity?

?? How important are frontal bonnet height and frontal bonnet length when they are used to predict vehicle aggressivity along with other vehicle features included in the regression equation?

The values of the correlation coefficients between the vehicle aggressivity index and wheelbase, frontal bonnet length and frontal bonnet height, separately, were found to be 0.679, 0.450 and 0.353 respectively. These results could indicate that wheelbase is the most important vehicle physical property in predicting aggressivity.

Importance of frontal bonnet height and frontal bonnet length with other vehicle features included in the regression equation was inferred directly from the statistical model. Because all regressor variables (the physical vehicle properties) used in this analysis were measured in the same units (in cm) then it

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was possible to interpret partial regression coefficients of the regression model as indicators of the relative importance of variables. The highest value of the estimated $\hat{?}$ coefficient will indicate the most influential parameter. It was found that $\hat{?}$ coefficient for frontal bonnet height had the highest value (0.044) indicating that frontal bonnet height is the most important factor in predicting vehicle aggressivity. In the case when 4WDs were excluded form the analysis, only one factor had the significant effect on vehicle aggressivity, namely, wheelbase.

The preliminary correlation analysis between the vehicle aggressivity index and year of vehicle manufacture showed the increasing linear trend (Fig. 1) indicating that, on average, newer cars seems to be more "aggressive". However, because of the small sample size, further analysis is needed to confirm this finding.

One of the shortcomings of this research is relatively small sample size used in the analysis. Therefore it is stressed that the results of this study should be viewed as preliminary only. Another shortcoming is the multiple regression model applied to empirically quantify the effect various measurable physical vehicle properties have on aggressivity. Thus far, it was assumed that effects are additive. It would be also of interest to investigate the multiplicative model. Further analysis is needed to find the best model to identify those physical properties of the vehicle.

CONCLUSIONS

The application of multiple regression analysis in the preliminary analysis allowed an identification of the physical features of the vehicle which are most likely to contribute to vehicle aggressivity. These were: frontal bonnet height, frontal bonnet length and wheelbase. In addition it was found, when comparing the results produced with 4WDs included and excluded from the analysis, that effects of frontal bonnet height and frontal bonnet length on vehicle aggressivity are most probably attributed to 4WDs.

Despite the questionability of the model applied, the data suggest that frontal bonnet height is the most important in predicting vehicle aggressivity.

Analysis of the relationship between the vehicle aggressivity ratings and year of vehicle manufacture showed that such a relationship exists. However, linearity of this relationship is questionable and should be further investigated before concluding that the newer cars are, on average, more "aggressive".

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