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# CORRELATION ANALYSIS OF VEHICLE FRONTAL IMPACT PARAMETERS

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Abstract. The article considers a possible improvement of road vehicle safety by using eCall – a system which initiates an emergency call in case of traffic accident. A possible way of better description of a frontal impact accident of a vehicle is examined and enriched by the information from the onboard e-call unit. In this article, we analyze results of frontal crash tests with different types of barriers and overlapping area and look for the correlation between the individual vehicle and collision parameters in order to provide a better description of the severity of the accident by the eCall system. The relation among the selected parameters is described using the correlation analysis.

Keywords: Crash test, eCall, cotrrelation.

## 1. Introduction

In a long-term timeframe, there is a noticeable decrease in the amount of road accidents, casualties and fatal victims of road accidents in Europe. It is mostly achieved thanks to newly accepted legislation measures increasing road safety and minimizing consequences of road accidents. One of these measures is a mandatory installation of the eCall system – an emergency call system in case of a road accident. The system is to be launched and installed on all newly produced vehicles in April 2018 [1].

Based on the information obtained from passive safety systems installed in the vehicle and additional eCall system sensors, the eCall system automatically detects a road accident and consequently sends a Minimum Set of Data (MSD) message to the emergency service and at the same time establishes a voice communication with 112 service.

The operator of the emergency service decides on the measures and safety services dispatched to the accident site based on the information obtained in the MSD message and from oral communication with passengers of the crashed vehicle.

The basic structure of the MSD message contains the following information about the vehicle and the accident:

- Version of MSD format;
- Identification of MSD;
- eCall activation type;
- VIN code for vehicle (ISO 3779)[2];
- Fuel type;
- Vehicle direction;
- Recent vehicle location N1, N2;
- Number of passengers (Locked safety belts).

A set of additional information, which can be used for more accurate description of consequences of accident, is described in this article. This was concluded based on results of series of crash tests.

## 2. Experiment Description

A background for the analysis is data obtained from a series of front impact collision of vehicles category M1. Results of these crash tests are shown in Table 1. Calculated resulting injury criteria coefficient HIC and 3 ms head criteria are represented in Table 2.

As it can be seen from Table 1 and 2, the constellations of test vehicles contain vehicles equipped with different types of passive safety systems. Activation of the frontal airbag was a monitored parameter. As for the collision partner, a solid barrier with a 100

The following parameters were selected for correlation analysis:

- **Overlapping of the frontal area** – Indicates overlapping of the frontal area of the test vehicle with the collision partner in percent;
- **Collision velocity ($\mathbf{v}_0$)** – calculated based on the video of the collision from high-speed cameras;
- **The weight of the vehicle** – calculated based on measurements performed on separate wheels with plate weights;
- **Kinetic energy of the vehicle($\mathbf{E}_k$)** – is calculated based on the vehicle weight, and collision velocity (Equation 1)

$$E_k = \frac{1}{2} * m * v^2, \tag{1}$$

where: $E_k$ – Kinetic energy of the vehicle right before the collision [J], $m$ – Weight of the vehicle [kg], $v$ – Collision velocity [m*s$^{-2}$];
- **Maximal acceleration of the vehicle body** – Estimated from the acceleration of the vehicle body during the collision in X direction;

| Test vehicle | Collision partner | Vehicle characteristics | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Overlap [%] | Front airbag | $V_0$ [km*h$^{-1}$] | m [kg] | $E_k$ [kJ] | $a_{max}$ [m*s$^{-2}$] | Deformation [mm] |
| Škoda Fabia | Rigid barrier | 100 | Yes | 50,77 | 1208 | 120,13 | 620 | 447 |
| Škoda Favorit | Rigid barrier | 100 | No | 47,3 | 875 | 75,53 | 459,8 | 508 |
| Škoda Rapid | Rigid barrier | 100 | Yes | 45 | 1235 | 96,48 | 378,1 | 416 |
| Škoda Rapid | Rigid barrier | 100 | No | 14,92 | 1122 | 9,64 | 115,6 | 127 |
| Renault 5 GTD | Rigid barrier | 40 | No | 52,2 | 938,6 | 98,67 | 345 | 700 |
| Škoda Roomster | Deform. barrier | 40 | Yes | 56,18 | 1542 | 187,76 | No | No |
| Škoda Fabia | Škoda Octavia | 33 | Yes | 50 | 1157 | 111,59 | 176 | 815 |

Table 1. Results of crash tests – characteristic of test vehicles.

| Test vehicle | Collision partner | Driver manikin | | Other manikin | | |
|---|---|---|---|---|---|---|
| | | $a_{max}$ [m*s$^{-2}$] | HIC [-] | Location in the vehicle | $a_{max}$ [m*s$^{-2}$] | HIC [-] |
| Škoda Fabia | Solid barrier | 510 | 302,94 | Passenger | 2277 | 4139 |
| Škoda Favorit | Solid barrier | 2490 | 2205,6 | Child P3 | 708,8 | 706 |
| Škoda Rapid | Solid barrier | 460 | 180,42 | Ne | Ne | No |
| Škoda Rapid | Solid barrier | No | Ne | Ne | Ne | No |
| Renault 5 GTD | Solid barrier | No | No | Child P3 | 856,6 | 612 |
| Škoda Roomster | Deform. barrier | No | 359,25 | Passenger | Ne | 358,64 |
| Škoda Fabia | Škoda Octavia | No | No | No | No | No |

Table 2. Results of crash tests – HIC criteria of test manikins.

- **Resulting deformation of the vehicle** ($\xi$) – Estimated from visual documentation of the test vehicle after the accident (photos and video from the high-speed cameras), based on comparison with photo documentation of the test vehicle before the collision;
- **Maximal acceleration of the manikin driver's head** ($a_{max}$) – Estimated from the acceleration acting on the driver manikin's head during the impact. The resulting acceleration curve was calculated from the accelerations of the manikin head in X, Y and Z axis based on the equation 2. The overall progress of result acceleration was then filtered with standard frequency filter CFC1000.

$$a_{celk} = \sqrt{a_x^2 + a_y^2 + a_z^2}, \tag{2}$$

where: $a_{celk}$ – Resulting acceleration [m*s$^{-2}$], $a_x, a_y, a_z$ – Acceleration of the manikin head measured in x, y, z [m*s$^{-2}$];

- **HIC criteria value for the driver manikin** – Head Injury criteria was calculated from the result acceleration curve based on the equation 3. In case there was no contact of the manikin head with the vehicle interior the time interval of 36 ms was selected for time $t_1$ to $t_2$ (estimated from the speed camera recordings), in casethere was a collision, a 15 ms time interval $t_1$ to $t_2$ was selected. HIC criteria value is then the maximum value in the selected interval for the result acceleration

$$HIC = \left[\frac{1}{t_1 - t_2} * \int_{t_1}^{t_2} adt\right]^{2,5} * (t_1 - t_2), \tag{3}$$

where: $HIC$ – Value of head injury criteria [-], $a$ – Result acceleration [g], $t_1$ – Start of the time interval for HIC calculation, $t_2$ – End of the time interval for HIC calculation.

Results of crash tests are summarized in Tables 1 and 2.

## 3. Correlation analysis of crash test results

Analysis of the crash tests results was made based on correlation analysis between selected parameters presented in Table 1 and 2, considering if it is suitable to use them for estimation of the severity of the accident by eCall system.

The relationship between parameters is expressed by a regression function using the least squares method (Equation 4)

$$
\begin{gathered}
y_i - \widehat{y}_i \\
y_i - a_{yx} + b_{yx} * x_i \\
\vdots \\
y_i - \widehat{y}_i \\
. \\
y_i - a_{yx} - b_{yx} * x_i \\
\vdots \\
F\big(a_{yx}, b_{yx}\big) = \frac{1}{n}\sum_{i=1}^{n}
\end{gathered} \tag{4}
$$

where: $\widehat{y}_i$ – Aligned value (theoretical), $y_i$ – Emperical values, $a_y x, b_y x$ – Equation coefficients.

The reliability of regression estimation was determined by the correlation coefficient $r_{yx}$. Correlation dependency is considered to be poor tight if the value of correlation coefficient is lower than 0.3. In case the value is higher than 0.8, then correlation dependency is considered to be very tight. If the value lies in the interval from 0.3 to 0.8 the correlation dependency is considered to be mild tight.

## 4. Dependency of the Vehicle Body Deformation from Collision Velocity

The dependency of the deformation of the vehicle from collision velocity is represented in Figure 1. From all the crash tests, only collisions with a rigid barrier with 100% overlapped were used for correlation analysis. These values are shown in the figure as blue dots with a line regression function. It is possible to calculate correlation coefficient from the coefficient of determination $R^2$ as it is shown in the Equation 5.

$$R = \sqrt{R^2} = \sqrt{0,9433} = 0,9712 \tag{5}$$

The resulting value of the regression coefficient is R = 0.9712 so we can consider correlation dependency as very tight. But a small amount of input data has to be considered.

In Figure 1 there are also shown other values which were not used for the regression analysis because of a different type of collision parameters. These are the data obtained from crash tests with the vehicle Renault 5 GDI, which was collided with a rigid barrier with 40% overlap, and a Skoda Fabia sedan, which was collided with another vehicle Skoda Octavia with 33% overlap. It is visible from Figure 1 that the value of the resulting deformation is increasing with decreasing overlap of the collision area.

## 5. The Dependency of Maximum Acceleration on the Kinetic Energy of the Vehicle

The next parameter that we consider in this research is the dependency between the value of maximum acceleration, which impacts the vehicle body during a crash, and the value of the vehicle's kinetic energy, which is transformed into the vehicle's body deformation during the collision. The values for individual vehicles are incorporated in the graph in Figure 2. As in the case of the dependency between vehicle body deformation and collision velocity, the regressive function describes only vehicles that suffered a frontal collision with a rigid barrier with 100% overlap. The values that are applicable to personal vehicles can also be found in the graph. To describe the dependency, an exponential regression function was chosen as it has a higher value for correlation coefficient than a linear function. The graph describing the equation of the regression function can be found in Figure 2, as well as the determination coefficient $R^2$. Equation 6 establishes the value of the correlation coefficient through a determination coefficient.

$$R = \sqrt{R^2} = \sqrt{0,9103} = 0,954 \tag{6}$$

According to the resulting value of the correlation coefficient R = 0,954 it is possible to see the correlation dependency as very high. However, it is necessary to take into consideration the small number of input values on the basis of which the function was solved.

The graph in Figure 2 also contains the values of acceleration for the Renault 5 GTD (40% overlap) and the Škoda Fabia sedan (33% overlap) with the lesser percentage of overlap. The graph demonstrates that the maximum acceleration influencing these vehicles with an equal value of the consumed kinetic energy in the case of vehicles with a 100% overlap is smaller. In the case of the Škoda Fabia sedan, however, part of the kinetic energy was given to another vehicle, Škoda Octavia, that was moved by 9,28 meters from its original position before the crash, as well as accelerated. For this reason, the tested vehicle was slowed down, which does not happen in case of frontal collision with a rigid barrier. This parameter, therefore, should not be considered.

## 6. The Dependencies of the HIC Criteria on the Speed of the Vehicle

In this chapter, the correlation of the possibility of the driver's head injury and the speed of the vehicle is considered in order to study the severity of injuries passengers of the car can suffer during a traffic accident. As it is clear from the results of the car collision that an airbag can have a serious impact on the resulting value of the HIC criteria, the correlation assumes that the airbag was used. The graph in Figure 3 presents values which also include the values established for the passenger mannequin. The linear regression function presented in the graph is applicable to a restraint system of a vehicle that has an airbag. The quantity of the correlation coefficient is calculated by equation 7.

$$R = \sqrt{R^2} = \sqrt{0,9024} = 0,9499 \tag{7}$$

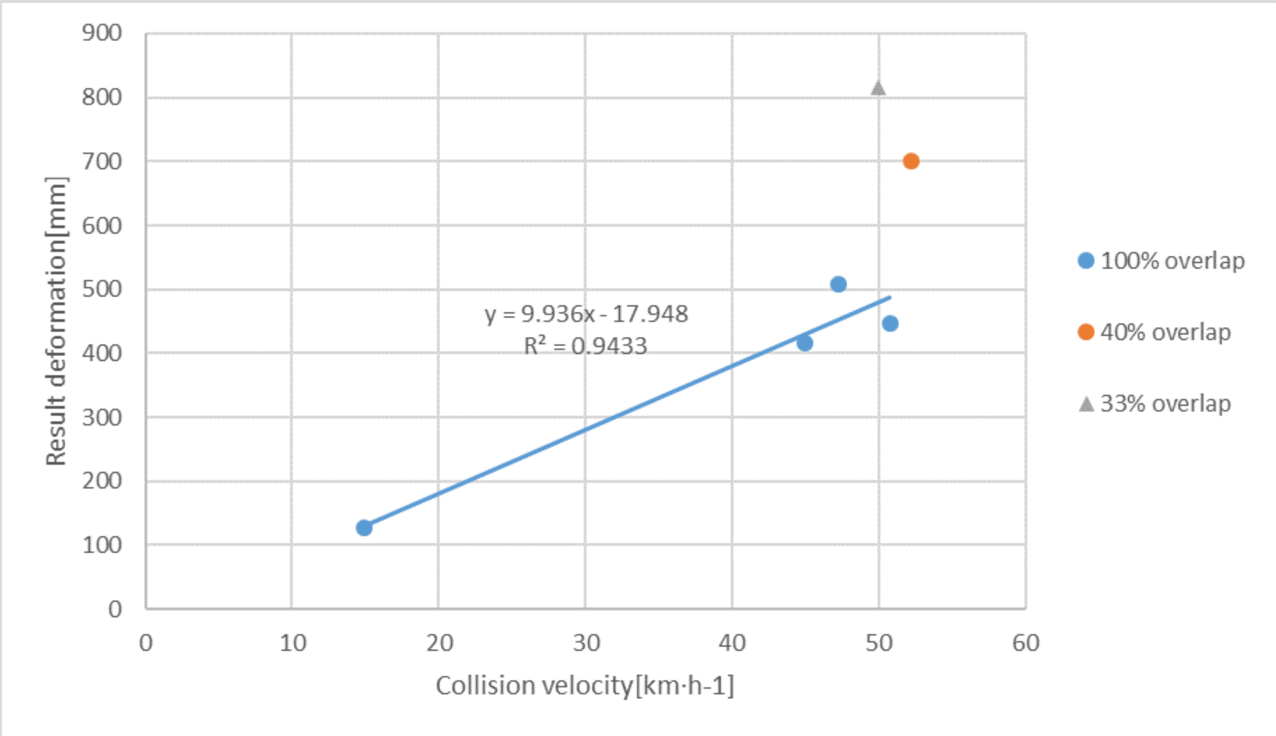


Figure 1. Dependency of the deformation of the vehicle from collision velocity.

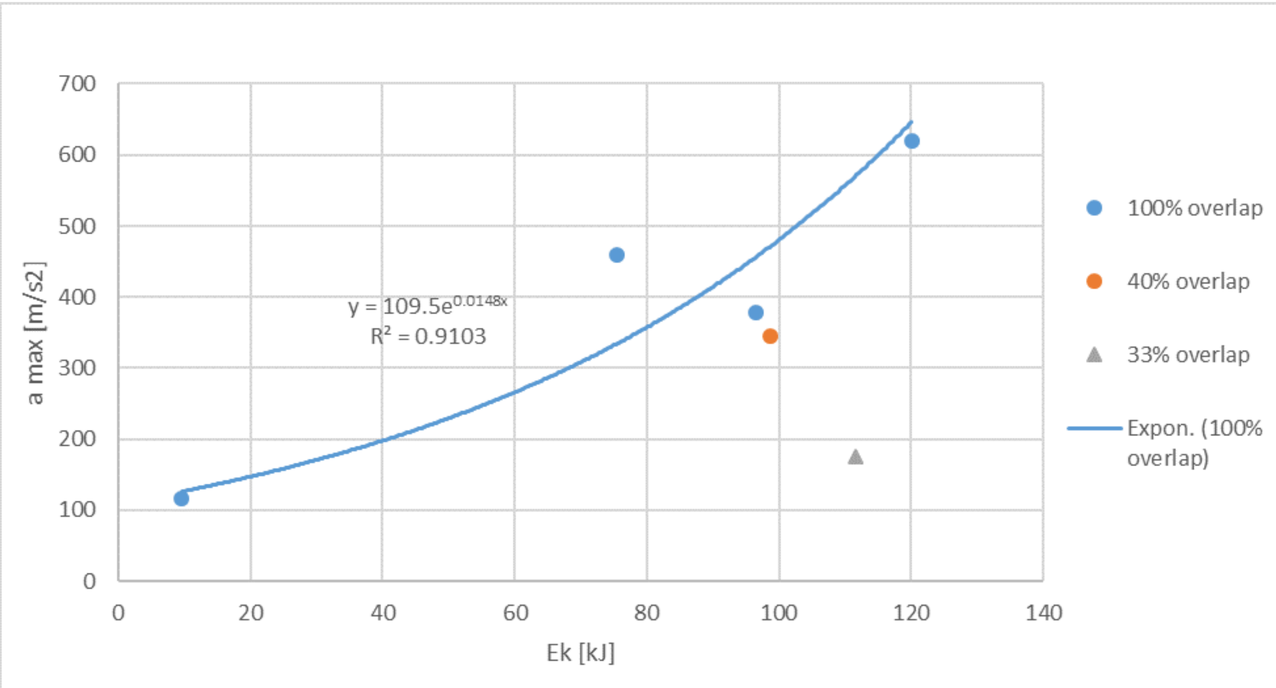


Figure 2. Dependency of the deformation of the vehicle from collision velocity.

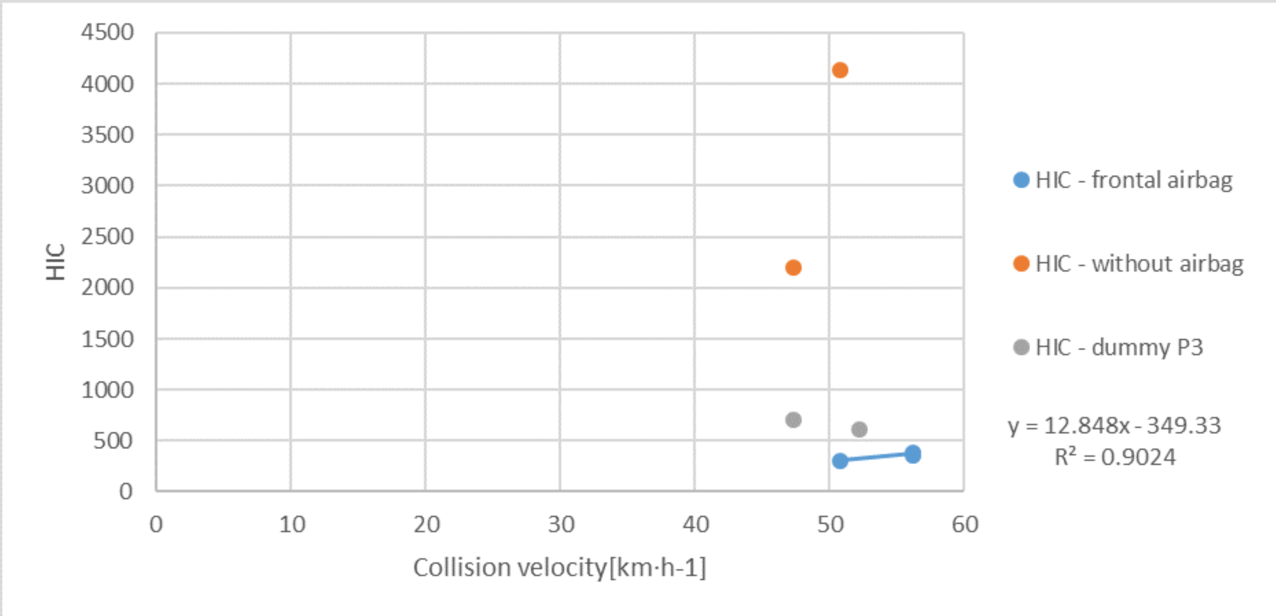


Figure 3. Dependency of the deformation of the vehicle from collision velocity.

According to the resulting value of the correlation coefficient R = 0,9499 it is possible to see the correlation dependency as very high. However, it is necessary to take into consideration the small number of input values on the basis of which the function was solved. To establish the regression function we have used only 3 input HIC values. In the case where we need to describe the seriousness of the injuries suffered by the passengers in a traffic accident, it is better to use the AIS method instead of the resulting value of the criterion of the injuries. The AIS method describes the seriousness of the injuries suffered by individual parts of the human body using a number in the 0 – 6 interval. This possibility is considered in the research described by [3] in the bibliography.

## 7. Conclusion

The problem of the estimation of the consequences arising from a vehicle collision was solved on the basis of establishing a dependency between the chosen vehicle parameters. In the chosen pairs of the parameters one quantity was possible to measure with eCall while another quantity was to be estimated. The dependency between the chosen parameters was described with a regression function and its accuracy was verified on the basis of the value of the correlation coefficient. In all three cases the accuracy of the quantity's dependence of the correlation coefficient $r_{xy}$ was verified. In all three cases, this coefficient came out to be higher than 0,8 and therefore we can establish the dependency between the chosen quantities to be very high. However, in considering the outcome we also have to bear in mind the low number of quantities on the basis of which the correlation analysis was carried out. This fact considerably undermines the reliability of the results. To strengthen the reliability of the results it is necessary to carry out a correlation on the basis of a higher number of crash tests with different impact velocities. Another way to acquire data for statistical analysis is to create a FEM or Multi-body model and to carry out a simulation of collision impact with simulation software. This would also allow for the repetition of the scenario with the same model and an easy change in input parameters.

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