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SIMULATION OF PEDESTRIAN THROW DISTANCE IN THE SOFTWARE PACKAGE PC-CRASH - COMPARISON WITH EXPERIMENT AND THEORY

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RESEARCH ARTICLE

ABSTRACT: The application of software simulations in traffic accidents reconstruction is becoming more and more pronounced. The PC Crash software package stands out as one of the most widely used tools for this purpose in Europe. One of the most important items in the analysis of vehicle-pedestrian collision is the speed of the car at the time of the collision and its impact on the pedestrian throw distance. In this paper, the influence of selected vehicle and pedestrian parameters on pedestrian throw distance was simulated using the PC crash software. The simulation results were compared with available experimental and analytical results from other sources in order to validate the PC Crash model of the vehicle-to-pedestrian accident.

KEY WORDS: *Accidents, pedestrian, PC Crash, vehicle*

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SIMULACIJA DUŽINE ODBAČAJA PEŠKA U PROGRAMSKOM PAKETU PC-CRASH - POREĐENJE EKSPERIMENTA I TEORIJE

REZIME: Primena softverskih simulacija u rekonstrukciji saobraćajnih nezgoda sve je izraženija. Programski paket PC Crash ističe se kao jedan od najčešće korišćenih alata za ovu svrhu u Evropi. Jedna od najvažnijih stavki u analizi sudara vozila i pešaka je brzina automobila u trenutku sudara i njen uticaj na rastojanje odbačaja pešaka. U ovom radu simuliran je uticaj odabranih parametara vozila i pešaka na rastojanje odbačaja pešaka pomoću programa *PC crash.* Rezultati simulacije su upoređeni sa dostupnim eksperimentalnim i analitičkim rezultatima iz drugih izvora kako bi se verifikovao PC Crash model sudara vozila-pešaka.

KLJUČNE REČI: *nezgoda, pešak, PC Crash, vozilo*

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INTRODUCTION

Pedestrians are the most vulnerable group of road users, especially because of their bodily insecurity. The increased number of traffic accidents involving pedestrians is the result of the increase in vehicle speed. Pedestrians account for about 24% of all seriously injured people in traffic, and when it comes to minor injuries, pedestrians account for about 11% [1].

The collision of vehicles and pedestrians leaves traces on both the vehicle and the pedestrians in the form of structural damage and in the form of injuries to the body. In order to determine the circumstances under which the accident occurred, it is necessary to analyse the both participants (the vehicle and the pedestrian). Due to the difference in mass between vehicles and pedestrians, as a result of an accident, pedestrian injuries are always more significant.

The most common classification of collisions includes: frontal collision (complete or partial), lateral collision and trampling. The kinematics of vehicle and pedestrian collisions depend on many factors, such as:

- vehicle shape,
- vehicle collision speed,
- pedestrian height,
- pedestrian speed,
- direction of pedestrian movement,
- position of the pedestrian at the time of the contact with the vehicle.

The impact of the vehicle on the pedestrian implies any contact of the body of the pedestrian with the vehicle. The strength of the injury depends on the age of the pedestrian. Older pedestrians over the age of 65 suffer significantly more injuries compared to younger pedestrians [1]. According to statistics in [2], the number of dead pedestrians aged 65 and over accounted for a total of 51% of the total number. Figure 1 [3] shows the death risk for pedestrians of different age depending on the impact speed. Given that elderly persons are often treated as a special group in traffic, numerous studies have been conducted on the influence of the age limit on the risk of injuries [4, 5].

Contemporary literature studies the relationship between vehicles and pedestrians. In [6] a mannequin model is used to assess the effect of impact velocity and mean deceleration on pedestrian throw distance. In [4], the authors were engaged in research on the dependence of the death outcome of pedestrians and the speed of the vehicle at the time of the collision in a completely frontal collision. They came to the conclusion that, as the speed of the car increases, so does the death rate of pedestrians. For example, at a speed of 50 km/h, the risk of death of pedestrians is twice as high as at a speed of 40 km/h, and four times higher than at a speed of 30 km/h. In [7], the authors also investigated the influence of vehicle speed and the speed of pedestrian movement on the occurrence of traffic accidents. Research [8] dealt with geometric modelling of accidents using various software packages. To simulate the

throw of pedestrians at the time of the collision with the vehicle, they used the software program PC Crash.

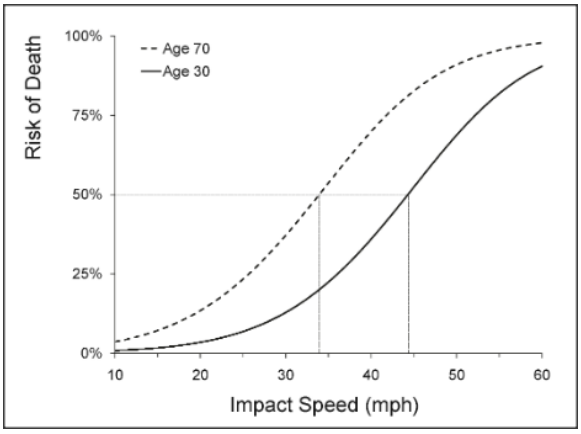

Figure 1. The percentage of pedestrian mortality depending on the impact speed [3].

In [9], an analysis of the distance of pedestrian throw based on the velocity speed was performed. Two databases were formed, one was a realistic measurement and the other database was formed based on simulations in the PC Crash software package. The results showed that there are differences in the use of these two bases by about 21%. However, the authors in [10] dealt with a similar analysis and came to the conclusion that there is a deviation of 10%. They concluded that the database used in the PC Crash software package could be used as a model for further data analysis.

In real conditions, in addition to the speed of the vehicle, it is necessary to include the braking distance, whether the vehicle has an ABS system or not and the pedestrian throw distance. Thus, in the paper [11], the authors reconstructed the vehicle-pedestrian collision using PC Crash and the exact value of the pedestrian throw distance was determined. They did a comparison of analysis data obtained in real conditions and with the help of simulation. The distance of pedestrian throw in real conditions was 11.2 m, while the simulation distance was 10.6 m. The deviation error was about 5%, which is allowed because, in the three-dimensional reconstruction of a traffic accident, when the error is less than 7%, the reconstruction is acceptable.

The paper [12] deals with the analysis of the variability of factors that influence the reconstruction of vehicle-pedestrian traffic accidents. Various anthropometric characteristics of the body were taken into account, such as height and weight, as well as the gender difference. Different positions of the pedestrian were analysed: - 0.5 m, 0 m, and + 0.5 m from the longitudinal axis of the vehicle, where 0 m corresponds to a central collision. Three different pedestrian movement speeds of 0, 2 km/h and 4 km/h were also taken into account, which correspond to a standing pedestrian, the pace of an elderly person, and a healthy person at a normal pace, respectively. Given that the coefficient of friction between pedestrians and road surface is always unknown, the following values were adopted: 0.4, 0.5, and 0.6. Based on the analysis, the results showed that four factors are significant for the experiment. These are: the height of the pedestrian, the angle of impact, the height of the vehicle hood, and the coefficient of friction between the pedestrian and the road surface.

Vehicle-pedestrian accidents account for more than 13% of the total number of accidents with victims [12]. In this paper, the PC Crash software was used as a vehicle-pedestrian

collision analysis software. PC Crash is software for traffic accident reconstruction analysis whose application has been recorded all over the world [13]. The technique of accident reconstruction is used in order to reduce the number of victims caused by these types of accidents. The latest technique, which is based on computer simulation, has reached a high level of development, the main goal of which is to determine the speed of a vehicle with a pedestrian collision [14]. In PC Crash, the pedestrian is modelled as a system of rigid bodies interconnected by joints [15, 16]. For the reasons mentioned, in this research, the distance of pedestrian throw was determined using the PC Crash software. The results obtained were compared to the results obtained by theory and by experimental research from [13] in order to verify the use of the mentioned software in vehicle-pedestrian accident reconstruction.

1. METHODS

The collision between a vehicle and a pedestrian is a complex event that is difficult to model. In order to develop effective measures to save pedestrians in traffic, it is necessary to properly understand the collision between vehicles and pedestrians. In addition, knowledge about the consequences of being exposed to a crash is required, as well as knowledge of the vehicle speed function itself. Knowledge of the mentioned measures provides useful information for the development of future pedestrian safety systems. It can also be used for designing vehicles and the pedestrian infrastructure itself.

In order to analyse the distance of pedestrian throw using the PC Crash, pedestrian modelling with body dimensions was performed, in the Multibody module. It is possible to get accurate information about the characteristics of the vehicle and the speed of the vehicle within the software database. Seven different vehicle speeds were taken into account: 38.46 km/h, 39.27 km/h, 43.61 km/h, 34.12 km/h, 55.04 km/h, 61.15 km/h and 64.86 km/h, while the weight of the pedestrian was 67 kg and the height was 1.78 m. The total weight of the vehicle was 1872 kg. Experimental data were taken from [13] for the purpose of comparison with simulation data.

The model of the Ford Crown Victoria 2005 vehicle was used in this paper. Figure 2 shows the loading of the vehicle into the PC Crash program, and figure 3 shows the setting of the vehicle speed.

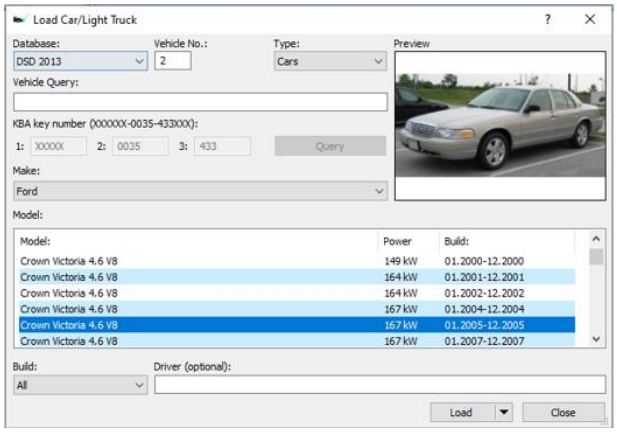

Figure 2. Importing the vehicle model into PC Crash software package.

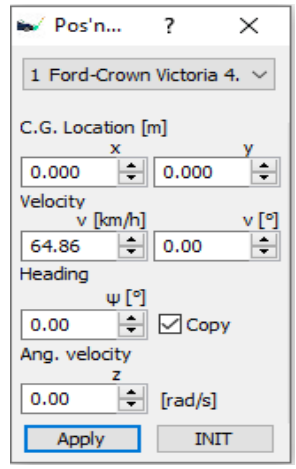

Figure 3. Setting the vehicle speed in the PC Crash software package.

In this paper, the frontal collision of vehicle and pedestrian was analysed. Based on various tests, the most commonly used theoretical dependence between the vehicle collision speed and the pedestrian throw distance can be presented in the following form [17]:

$$S_{od} = \frac{v_s^2}{144}\left(\pm 10\%\right), \tag{1}$$

where:

- S_{od}, m - distance from the place of collision to the final position of the pedestrian (pedestrian throw distance) and
- v_s, $\frac{\text{m}}{\text{s}}$ - impact speed.

Value 144 in equation (1) has the dimension of acceleration. Research has shown that equation (1) can be used for real accidents, but the results deviate by ± 10%.

In this paper, empiric Dekra formula (2) is used for the analytical calculation of the pedestrian throw distance [18] and various comparisons:

$$s = 2.5 + 0.38448 \cdot v + 0.05858 \cdot \frac{v^2}{a_{car}}, \tag{2}$$

where:

- v, $\frac{\text{m}}{\text{s}}$ – impact speed,
- s, m – pedestrian throw distance and
- a_{car}, $\frac{m}{s^2}$ – average car deceleration.

The three-dimensional Multibody model, which is a subroutine of PC Crash software, is based on the principle of biomechanics [19]. For this reason, it can be concluded that it is the best way to investigate this type of accident. Many input data are recommended as default data defined by the software, while others need to be entered by the user (figure 4).

After loading the pedestrian, it is possible to modify certain parameters of the pedestrian body. In the end, 3D-DXF models in PC Crash are used to make the simulation of a pedestrian-vehicle collision look as realistic as possible.

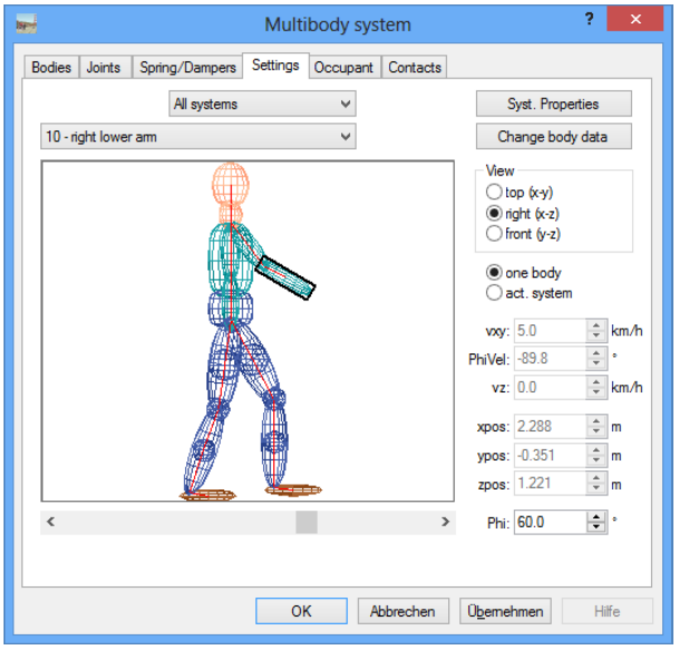

Figure 4. Input of pedestrian's parameters in the PC Crash software package.

2. RESULTS AND DISCUSSION

The obtained PC Crash software results for the pedestrian throw distance depending on the impact speed of the vehicle are shown in table 1, together with the data obtained experimentally [13] and analytically. After the analysis, a comparative presentation of all results was given.

Table 1. Values of pedestrian throw distance for different vehicle speeds

Test number	Vehicle impact speed, km/h	Pedestrian throw distance, m		
		Experimental [13]	Analytic	PC Crash
1	38.46	10.61	10.49	10.54
2	39.27	11.34	10.84	10.94
3	43.61	14.78	12.74	13.25
4	34.12	9.05	8.76	8.65
5	55.04	17.53	18.48	16.98
6	61.15	24.75	21.95	22.90
7	64.86	26.03	24.20	25.23

Based on table 1, it can be concluded that, as the impact speed of the vehicle increases, so does the throw distance of pedestrians. This increase was observed in all three types of analysis: experimental, analytical, and in the PC Crash program, figure 5.

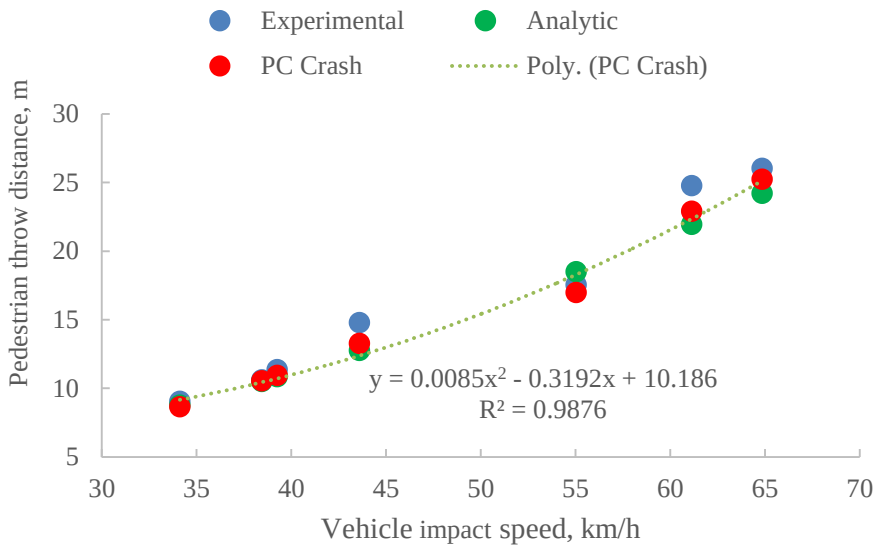

Figure 5. Pedestrian throw distance depending on impact speed.

Figure 5 shows a strong (parabolic) correlation between the pedestrian throw distance and the vehicle impact speed in PC Crash simulation results (R^2=0.9876). The smallest value of the pedestrian throw distance of 8.65 m was obtained numerically, using the PC Crash program, for impact speed of 34.12 km/h. The highest value of the pedestrian throw distance of 26.03 m was obtained by experimental determination, for impact speed of 64.86 km/h.

The descriptive statistical characteristics of pedestrian throw distance for the three observed types of results (standard error, sample variance, mean, standard deviation and kurtosis) are presented in table 2.

Table 2. Descriptive characteristics of pedestrian throw distance

	Pedestrian throw distance, m		
	Experimental	Analytic	PC Crash
Standard error	2.58	2.32	2.43
Sample variance	46.57	37.65	41.50
Mean	16.30	15.35	15.50
Standard deviation	6.82	6.13	6.44
Kurtosis	-1.42	-1.77	-1.27

Figure 6 shows relative deviations of the results for pedestrian throw distance obtained by analytical formula and PC Crash from the same results obtained by the experiment. It can be seen that the results of simulation done using PC Crash software show smaller deviations from the corresponding experimental data. Maximal relative deviation of the PC Crash simulation data is around 10%, while maximal relative deviation of the analytically obtained data is around 14%.

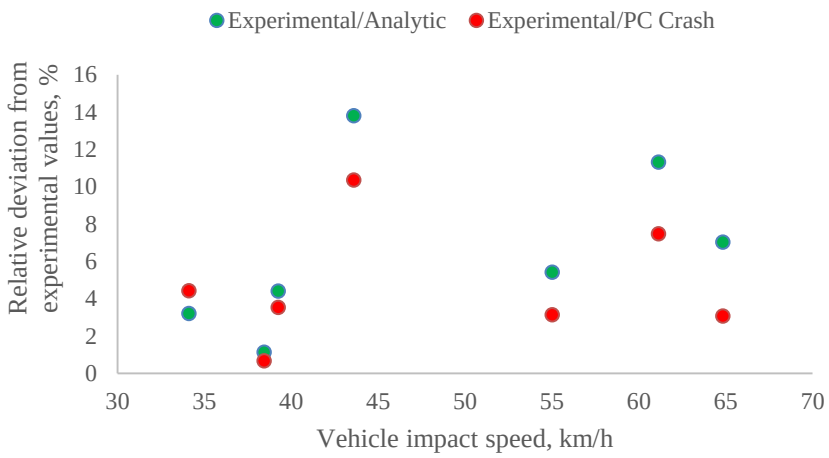

Figure 6. Relative deviation of the simulation data from the experimentally obtained values.

The analysis of the relative variations of the simulation results from the experimental data imply that the results obtained by using PC Crash software are closer to experimental data than data obtained by analytical calculations. This confirms the justification of using the PC Crash software in simulation of vehicle-pedestrian accidents when calculating pedestrian throw distances.

3. CONCLUSIONS

The application of computer programs for the analysis of traffic accidents enables a more precise analysis of the elements of the traffic accident, taking into account the place of the collision, the collision speed as well as the circumstances under which the traffic accident occurred.

PC Crash is a traffic accident simulation program that can simulate many traffic accident situations. In this research, PC Crash was used is the analysis of pedestrian throw distance depending on the impact speed of the vehicle. On the basis of simulations performed with different values of speed, pedestrian throw distances were obtained.

Based on various comparisons, it was found that the pedestrian model in PC Crash gives good estimates for determining the pedestrian throw distance, better than analytical model. Different vehicle shapes and pedestrian kinematics can be taken into account in the analysis. The pedestrian model in PC Crash proved to be easier to analyse, compared to the analytical way of analysis, because all the parameters that influenced the occurrence of the accident could be taken into account.

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