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Pedestrian-Vehicle Accidents Reconstruction with PC-Crash®: Sensibility Analysis of Factors Variation

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ABSTRACT

This paper describes the main findings of a study performed by INSIA-UPM about the improvement of the reconstruction process of real world vehicle-pedestrian accidents using PC-Crash® software, aimed to develop a software tool for the estimation of the variability of the collision speed due to the lack of real values of some parameters required during the reconstruction task.

The methodology has been based on a sensibility analysis of the factors variation. A total of 9 factors have been analyzed with the objective of identifying which ones were significant. Four of them (pedestrian height, collision angle, hood height and pedestrian-road friction coefficient) were significant and were included in a full factorial experiment with the collision speed as an additional factor in order to obtain a regression model with up to third level interactions. Two different factorial experiments with the same structure have been performed because of pedestrian gender differences.

The tool has been created as a collision speed predictor based on the regression models obtained, using the 4 significant factors and the projection distance measured or estimated in the accident site.

The tool has been used on the analysis of real-world reconstructed accidents occurred in the city of Madrid (Spain). The results have been adequate in most cases with less than 10% of deviation between the predicted speed and the one estimated in the reconstructions.

1. INTRODUCTION

Vehicle-pedestrian accidents are the great forgotten by the media at the time of making balance of traffic accident victims. However, one out of five fatalities in road accidents was a pedestrian according to the latest statistics published in Spain (DGT, 2015). Vehicle-pedestrian accidents account for more than 13% of the total number of accidents with

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victims, with relevance highlighted in groups such as children and the elderly.

Technics for reconstructing vehicle-pedestrian accidents are used in accidentology with the aim of reducing the number of victims caused by these accidents. These technics have evolved significantly from the early eighties of the last century. The recent technics based on computer simulation have reached a high level of development, despite that, the main objective is still the evaluation of the vehicle speed when colliding with the pedestrian.

This objective may seem easy to reach, but behind it there is a complex problem influenced by a great number of factors related to the vehicle, the pedestrian and the road. A crucial phase that apparently has not changed significantly from origins is obtaining data from the accident site. Most of the reconstruction accuracy depends on the quality of the information collected in this first phase.

Nowadays, the collected information is used as baseline and support data in accident reconstruction programs as used in this project, PC-Crash®. PC-Crash® is a specialized software for traffic accidents reconstruction with a broad variety of parameters. Some of the factors are used on the reconstructions despite their values are unknown because of the difficulty for being measured easily, as the friction coefficient between the pedestrian and the ground, or because the emergency services do not supply them, as the pedestrian data. An additional information from the accident site is the geometrical one, which is collected as a sketch that can be easily used as a template in PC-Crash®. The projection distance of the pedestrian is a reference variable for the entire project that is known by the sketch.

This project is based on that factors variability and tries to analyze what factors from those normally used are truly significant. Then, the identified factors should be analyzed in order to know their influence on speed variability when real values are not available for some of them during the reconstruction tasks.

2. OBJECTIVES

The main objective is the development of an optimization tool for vehicle-pedestrian accident reconstruction based on a sensibility analysis of PC-Crash significant factors. This tool should be useful for approaching reconstructions and for their verification.

3. METHODOLOGY

The development of this project is divided into several phases with partial objectives.

3.1 FACTORS SELECTION

The first phase is centered on factors selection and on determining the variation range of each one. A group of nine factors related to the vehicle, the pedestrian and the site is selected. The factors are the following: pedestrian height and weight, angle and position of

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the pedestrian to the longitudinal axis of the vehicle, pedestrian speed, vehicle mass, height of the frontal edge of the hood, hood length and friction coefficient between the pedestrian and the ground. Out of this group, vehicle speed is considered a significant factor regarding the projection distance of the pedestrian because of evident reasons, and its range of variation goes from 20 to 60 km/h.

The other factors take significant values from a range, such as percentile 5, median and percentile 95 using data from studies or samples, in other cases the election is done in a similar way.

Pedestrian height and weight are anthropometric data from population studies and these data are different for men and women. The pedestrian angle takes the values 0°, 45° and 90°, being 90° the most usual, corresponding to a pedestrian crossing perpendicularly to vehicle. The pedestrian position to the longitudinal axis of the vehicle takes the values -0.5 m, 0 m and +0.5 m, being 0 m the most usual, corresponding to a centered collision. Pedestrian speed takes the values 0, 2 and 4 km/h, corresponding to a stopped pedestrian, an elderly person pace and a healthy person usual pace respectively, all suggested by AASHTO (Fricke, 1990).

The values for the vehicle mass are taken from a sample composed by all the vehicles tested by EURONCAP until September 2014, except business vans and pick-ups. The data about hood length and height come from an INSIA own database with measures of vehicles profile.

The friction coefficient between the pedestrian and the ground is always an unknown data. A reasonable range for concrete and asphalt goes from 0.4 to 0.65 according to Fricke (1990), so the selected values are 0.4, 0.5 and 0.6 for this factor.

Factor	Low	Medium	High
Pedestrian height(M)	1.58 m	1.70 m	1.82 m
Pedestrian height (F)	1.49 m	1.60 m	1.70 m
Pedestrian weight (M)	58.6 kg	75 kg	95.8 kg
Pedestrian weight (M)	48.1 kg	59 kg	77 kg
Vehicle mass	885 kg	1330 kg	1910 kg
Hood height	0.60 m	0.71 m	0.82 m
Hood length	0.83 m	0.92 m	1.01 m
Pedestrian angle	0º	45º	90º
Pedestrian speed	0 km/h	2 km/h	4 km/h
Pedestrian position to the longitudinal axis of the vehicle	-0.5 m	0 m	+ 0.5 m
Friction coefficient between the pedestrian and the ground	0.4	0.5	0.6

Table 1 – Selected factors and their values

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3.2 SIGNIFICANT FACTORS IDENTIFICATION

The following phase has the aim of evaluating which factors are significant regarding to the pedestrian projection distance. Several simulation series are carried on over a standardized accident scenery. At the starting situation of the scenery, all the factors except the pedestrian angle are stablished to their intermediate values. The pedestrian angle is stablished to 90° because it is the most usual situation. In all simulations, the vehicle brakes at maximum with ABS active and the steering wheel in centered position. Two sceneries are generated, one for each gender, because they have to be simulated separately due to the anthropometric differences. Each factor is evaluated independently at 20, 30, 40, 50 and 60 km/h for the three levels. For each gender, 135 simulations are carried on.

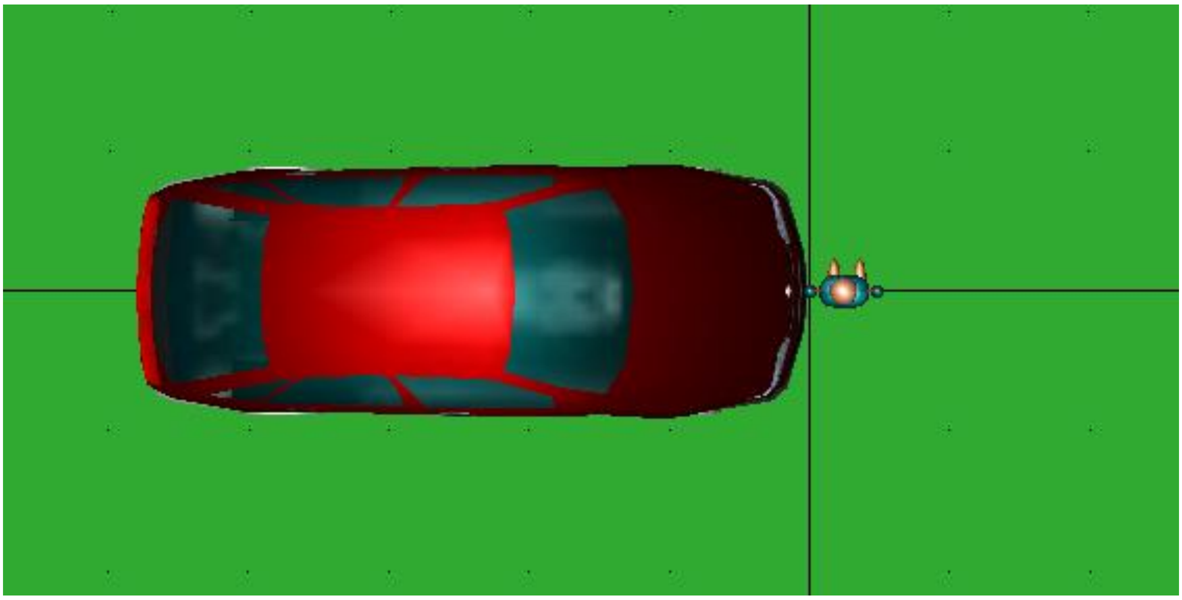

Fig. 1 – Standardized accident scenery

Once all results are collected, they are analyzed using a one factor ANOVA. The results show that four out of nine factors are significant ($\alpha < 0.05$): friction coefficient between the pedestrian and the ground, height of the frontal edge of the hood, pedestrian height and pedestrian angle to the vehicle axis. The five other factors are discarded for the following experiments and are fixed to their intermediate values.

3.3 TOOL DEVELOPMENT

The aim of this phase is the development of the optimization tool with the significant factors. Design of experiments technics are used for creating two experiments matrices, one for each gender, with all the combinations for the four identified factors and vehicle speed as additional factor with five levels (20, 30, 40, 50 and 60 km/h). Each matrix contains 405 experiments ($3^4 \cdot 5^1$) so the tool is based on 810 experiments. Each simulation is carried on using a standardized scenery as used on previous phase. A total of 81 standardized bases are created to carry on five experiment each; five speed levels. In order to avoid interferences between simulations, each experiment is carried on over blank copies of the bases.

The matrices filled up with the results are analyzed through multifactorial ANOVA technics integrated in a specialized software. Significant interactions ($\alpha < 0.05$) up to third level are allowed, the single condition is generating a hierarchical model. The two matrices generate

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two models with the same characteristics, four third-level interactions, seven second-level interactions and the five primary significant factors.

Each multifactor regression model generates a parameter interpolator for calculating the equation terms when the real values of some factors are known and these are within the ranges.

The interpolator and the model equation constitute the tool that allows collision speed calculations through the pedestrian projection distance and the available information about the four significant factors. In addition, it allows revising reconstructed accidents. The model can calculate an estimated projection distance with the reconstruction speed and the values of the other factors and compare it with the real distance.

3.4 VALIDATION

The validation is based on a database of reconstructed accidents occurred in city of Madrid (Spain) from a project developed between 2002 and 2006.

For each accident, the projection distance is calculated through the model equation with the factors values from the reconstruction. The equation terms should be calculated using the interpolator because the values used rarely coincide with the factors levels.

The next step is calculating speed ranges for the accidents using the model equation with the speed as an unknown and the projection distance as a known data. Considering that the values of two factors are totally unknown; pedestrian angle and friction coefficient, pedestrian height could be known and hood height is known through vehicle information, the combinations to be calculated are 9 if pedestrian height is known and 27 if it is unknown. The results in each accident are the maximum, the minimum and the mean speed predicted by the tool and are compared with the speed from the original reconstruction.

Pedestrian Height	Pedestrian Angle	Friction Coefficient	Hood Height	Speed	Distance
1,61	90	0,6	0,81	36,6	14,20
1,61	0	0,4	0,81	36,32	14,20
1,61	0	0,5	0,81	38,52	14,20
1,61	0	0,6	0,81	39,94	14,20
1,61	45	0,4	0,81	36,15	14,20
1,61	45	0,5	0,81	38,11	14,20
1,61	45	0,6	0,81	39,37	14,20
1,61	90	0,4	0,81	36,21	14,20
1,61	90	0,5	0,81	38,17	14,20
1,61	90	0,6	0,81	39,43	14,20

Table 2 – Predictions from accident num. 5

4. RESULTS

The tool is applied to a 29 accidents series from the mentioned database. The following table compares the speed from the reconstruction (Reconstr. Speed) with the predicted mean speed (Med. Pred. Speed), and shows the maximum (Max. Pred. Speed) and the minimum (Min. Pred. Speed) of the prediction ranges.

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Gender	Height	Accident	Reconstr. Dist.	Reconstr. Speed	Min. Pred. Speed	Max. Pred. Speed	Med. Pred. Speed	% Rec. Speed/Med. Speed
Man	Known	13	7,64	34,00	24,72	28,02	26,52	28,21%
Man	Known	1	7,70	34,00	24,82	28,51	26,91	26,35%
Woman	Unknown	3	11,88	44,00	32,48	37,30	34,83	26,33%
Man	Known	33	15,51	47,70	37,10	41,84	39,48	20,82%
Woman	Known	4	9,46	36,00	28,87	32,33	30,46	18,19%
Man	Known	31	13,13	43,00	34,44	38,68	36,54	17,68%
Woman	Unknown	9	6,51	28,00	22,79	26,44	24,25	15,46%
Man	Known	24	17,98	50,00	41,93	46,63	44,18	13,17%
Woman	Known	18	13,87	43,00	35,43	41,64	38,75	10,97%
Woman	Unknown	21	10,38	35,80	30,61	35,26	32,66	9,61%
Woman	Known	23	30,12	64,00	54,71	64,29	58,77	8,90%
Man	Unknown	37	18,57	49,00	41,91	48,62	45,10	8,65%
Woman	Known	10	8,27	31,50	26,77	31,24	29,00	8,62%
Woman	Known	12	3,03	17,00	15,10	16,50	15,77	7,80%
Man	Known	16	3,72	19,00	17,11	18,45	17,70	7,34%
Woman	Known	32	6,96	23,50	20,61	24,18	22,36	5,10%
Woman	Known	36	19,32	43,00	41,16	47,81	44,35	-3,04%
Woman	Unknown	14	5,00	20,00	18,78	22,66	20,71	-3,43%
Man	Unknown	17	5,11	20,00	19,14	22,42	20,75	-3,61%
Woman	Known	5	14,20	36,60	36,15	39,94	38,02	-3,73%
Woman	Known	19	10,91	31,50	31,81	36,00	33,78	-6,75%
Man	Unknown	35	11,14	31,00	31,62	35,18	33,39	-7,16%
Woman	Known	15	9,46	28,00	28,75	32,62	31,04	-9,79%
Woman	Known	27	11,66	30,00	32,17	35,44	33,89	-11,48%
Woman	Known	8	9,97	28,00	30,74	33,34	32,09	-12,75%
Woman	Known	39	24,44	45,00	49,31	56,79	52,59	-14,43%
Woman	Unknown	22	4,21	16,00	17,58	20,26	18,87	-15,21%
Man	Known	25	4,55	16,00	17,33	20,13	18,92	-15,43%
Woman	Known	6	4,49	16,00	19,11	20,35	19,66	-18,62%

Table 3 – Validation results

The differences below 10% are remarked in green, between 10% and 20% in orange and over 20% in red. In accidents 13 and 33, the pedestrians are too tall for the predictor and it is working out of range. And in accidents 1 and 3, the vehicles tried to avoid the pedestrians resulting in not centered collisions with lateral escape trajectories.

5. CONCLUSIONS

The significant factors constitute a more reduced group than initially planned. That makes the design of experiments feasible enough, but does not inhibit to obtain a complex model due to factor interactions.

The developed tool allows predicting the collision speed with admissible deviations in view of the obtained results. Uncertainty intervals are reduced depending on known factors, since it is necessary to calculate fewer predictions.

The tool is restricted to frontal collisions and limited by the variation range of the factors. However, it can be used for quick collision speed estimations without any specific reconstruction software and as a first approaching in a reconstruction process, providing a range of speed and limiting the values of significant factors.

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