COMPARATIVE STUDY OF THE THROW DISTANCE OF PEDESTRIANS IN FRONTAL COLLISIONS WITH VEHICLES USING COMPUTER SIMULATION

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Abstract: The pedestrian throw distance in the event of a frontal collision with a motor vehicle is of utmost importance, as vehicle speed at the moment of impact can be determined. This is a kind of analysis that is many times required and performed within the technical, judicial or extra-judicial technical expertise, in the case of road accidents involving pedestrians. The result of these expertise is particularly important both from the point of view of the criminal investigation, thus being able to establish guilt from legal point of view, as well as from the point of view of civil legal claims, as victims may seek compensation if the driver of the vehicle has violated the speed restrictions set for the road sector in which the accident occurred. In the paper a comparison is made between the results obtained based on equations used in specific literature and the results of the simulations performed in the specialized software called Virtual Crash.

Keywords: VCrash, impact, throw distance, pedestrian

1. INTRODUCTION

Every year thousands of people lose their life or are seriously injured in accidents on EU roads. Based on the statistics reported by Eurostat for 2018, it is shown that with an average of 49 road deaths per one million inhabitants, European roads are by far the safest in the world.

For the majority of Member States, the road fatality rate was below 60 deaths per million inhabitants in 2018.

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Unfortunately, there are two EU Member States that recorded a fatality rate higher than 80 deaths per million inhabitants. The countries with the highest fatality rate were Bulgaria (96/million), Romania (88/million), Latvia (78/million) and Croatia (77/million). It is also a fact that Romania has placed 1st or 2nd in this statistic for the last decade.

Based on the same statistics, the most vulnerable road users were, in order: pedestrians, cyclists, motorcyclists and the elderly. With demographic changes and the ongoing trend towards active and sustainable mobility, these groups are expected to represent a higher proportion of road users in the future, and will require particular attention.

Specifically, out of the total deaths caused by road accidents at EU level in 2018, 22% of them are pedestrians. However, in Romania, out of the total deaths caused by road accidents, this percentage is almost double as compared to EU, with more than 42% of deaths being recorded among pedestrians. [1].

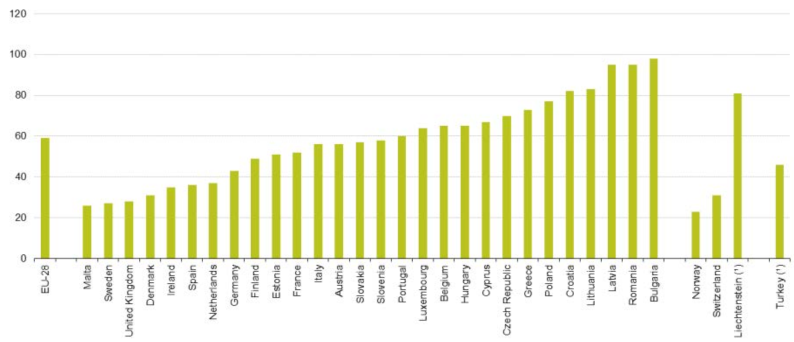


Fig.1 Country rankings for fatality per million inhabitants. (Source: Eurostat)

The larger number of accidents involving pedestrians, automatically leads to the need for a much higher number of technical expertise to be conducted in Romania as compared to the EU level. These technical expertise can be done either by the classical methods, which involve calculations based either on analytical formulas or on simplified, statistical analysis resulting from worldwide data collection of 30-40 years. In the last years, the use of computers and accident reconstruction specific software, offers a faster, more accurate and visual results by modeling and simulation.

VCrash, short for Virtual Crash, is a new generation software for the simulation of accidents. It takes advantage of the latest hardware and software developments, which allows increasingly complex realtime calculations to be performed on a PC. For maximum versatility, VCrash simulation results can be viewed in scale plan, 3D view, numerous diagrams and tables are generated.

This software has a complete database of vehicles with their full characteristics, various objects, and pedestrians which can all be introduced in the simulation interface. Mass characteristics, direction or travel speed can be exactly defined.

2. THEORETICAL ASPECTS OF VEHICLE AND PEDESTRIAN COLLISIONS

The collision of a vehicle with a pedestrian must be approached differently than a collision involving only vehicles, because of some fundamental differences. Pedestrians move at the moment of impact at much lower speeds than vehicles. Due to the mass differences and the negligible friction between the pedestrian and the vehicle, the pedestrian will be thrown most of the time in the same direction as the vehicle was traveling. There is also a close connection between the geometry of the front part of the vehicle and the trajectory, speed and acceleration of the pedestrian after the collision [2].

Theoretically, there are four types of vehicle-pedestrian collisions that can be defined, distinguished by movement of the pedestrian after impact:

- frontal collisions without rotation (in case of impact with flat surfaces higher than the pedestrian, such as front ends of trucks, buses or some vans). In such collisions a single impact takes place with the vehicle, in a direction parallel to the road;

- frontal collisions with the rotation of the head. Due to the small frontal contact surface situated below the center of gravity of the pedestrian and the body flexibility, the pedestrian body rolls on the engine hood and the head hits the windshield or dome if the speed is high enough, so a second impact takes place, after which the body projected forward at a certain angle α compared to the roadway;

- collisions with transport, when the pedestrian remains for a certain period of time in contact with the vehicle front, and then slides forward during the energetic braking of the vehicle;

- collisions with catapulting, which start as a frontal collision with rotation, but due to the high speed, pedestrians continue their movement on the dome towards the rear of the vehicle. A particular case is when the pedestrian is hit with the side of the front part, and his body rolls and is thrown sidewise, outside the direction of travel of the vehicle, without having a secondary impact.

The purpose of the reconstruction of the vehicle-pedestrian collision is usually the determination the speed of the vehicle. Reconstruction can be approached in several ways, but each of them is based on the knowledge of at least one of the following, as measured at the accident scene:

- S_p throwing distance, defined as the distance between the initial contact point of the vehicle with the pedestrian and the final position where the body stops on the road;

- the body slip distance S, defined as the distance between the initial point of contact with the road and the final position of the pedestrian after the accident.

Reconstruction is also possible if the distance S_k is known, between the final stopping positions of both the pedestrian and the vehicle, but only if the distance S_j is known, between the moment of impact until the moment of braking.

3. METHODS OF RECONSTRUCTION OF MOTOR VEHICLE AND PEDESTRIAN COLLISIONS

A first method is to use statistical formula based on experimental tests with dummies or old research using corpses. A second method uses equations of theoretical mechanics. The third approach is a combination of the two, in which the theoretical equations are correlated with the results of the experimental tests. And finally, we have modeling and simulation of these events using computer and dedicated software.

The statistical model is advantageous because the equations are simple and easy to apply. On the other hand, their applicability is limited to data gathered during experimental tests. Theoretical models cover a much wider field, although in some particular situations they proved to be less precise than the statistical ones. The combined approach gives better results and has a broader applicability.

For the purpose of the study, various equations used worldwide for theoretical determinations of speed and throw distance are presented.

In the case of frontal collisions, when the initial height of the pedestrian's centre of mass is neglected, Wood [3] showed that the relationship between vehicle speed and pedestrian throw distance is:

$$W_a = C_W \cdot \sqrt{S_p} \quad [km/h] \tag{1}$$

where: C_w is a coefficient that depends on various parameters including the angle of the bonnet and the deceleration of the vehicle; W_a is the speed of the vehicle at the moment of the collision [km/h]; S_p is the pedestrian throwing distance [m].

In the case of frontal collisions without rolling, based on experimental determinations, in the USA the following values are used: C_w = 7,308 ... 14,04 - for children and C_w = 7,02 ... 13,57 - for adults. At collisions with roll, the values are also provided for adults C_w = 9 ... 16.2, with the average value C_w = 12.

In Europe, researchers Hill [4] and Dettinger [5] collected data from real accidents. The dataset published by Hill contains data from 26 accidents in the Birmingham area of England during a three year period ending in 1987. Also given in Hill's paper are values of the coefficient of friction between the vehicle and the road, measured in tests. Dettinger's paper contains data from 12 accidents, compiled by the DEKRA Accident Research Agency in Stuttgart, Germany, in the years before 1996. Comparing the two it is clear that the datasets of Dettinger and of Hill have almost the same statistical properties, so in order to obtain an accurate model of the dependence of throw distance on vehicle speed is to use a value of 3.58 for the constant that also appears in the Wood formula. This is the Hill/Dettinger model:

$$\begin{gathered} W_a = 3.58 \cdot \sqrt{S_p} \quad [m/s] \text{ or} \\ W_a = 3.6 \cdot 3.58 \cdot \sqrt{S_p} = 12.89 \cdot \sqrt{S_p} \, [km/h] \end{gathered} \tag{2}$$

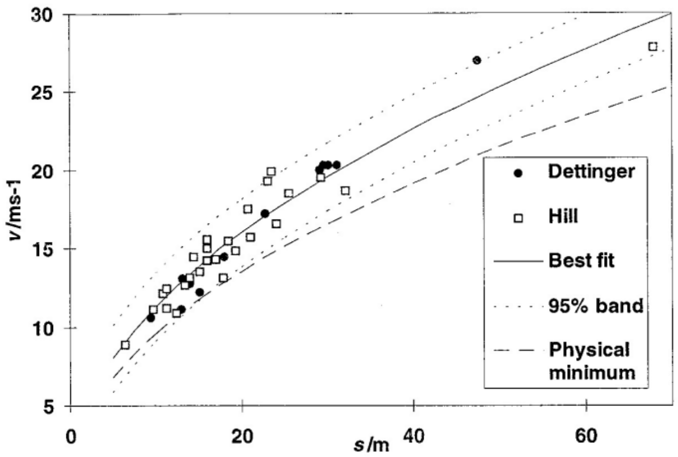


Fig. 1. Pedestrian throw distance and vehicle speed for Hill and Dettinger. (Source [6])

Another approach to the determination of the dependence of throw distance on vehicle speed is based on research conducted by Rau and Otte [7], which provides more exact results on a wider spectrum of speeds:

$$S_p = 0,0052 \cdot {W_a}^2 + 0,0783 \cdot W_a \ \ [m]$$
$$W_a = -7,528 + \sqrt{192,307 \cdot S_p + 56,678} \ \ [km/h] \qquad (3)$$

Figure 2 shows the distribution of results for the latter model falls inside the gray band (corresponding to 95 percent).

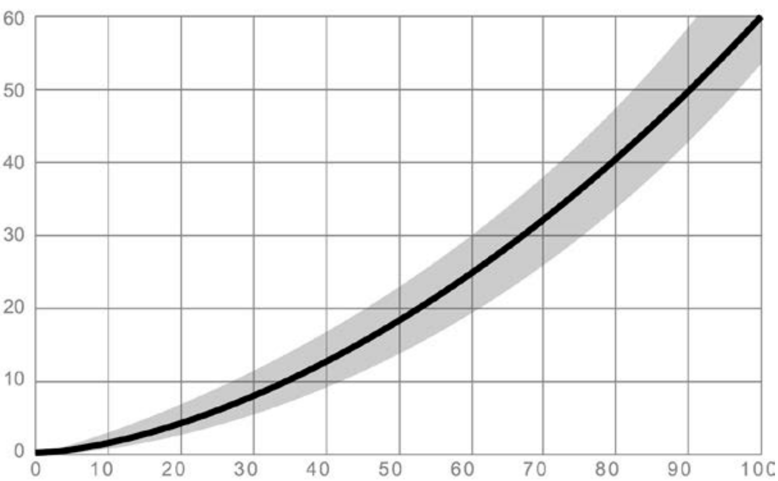
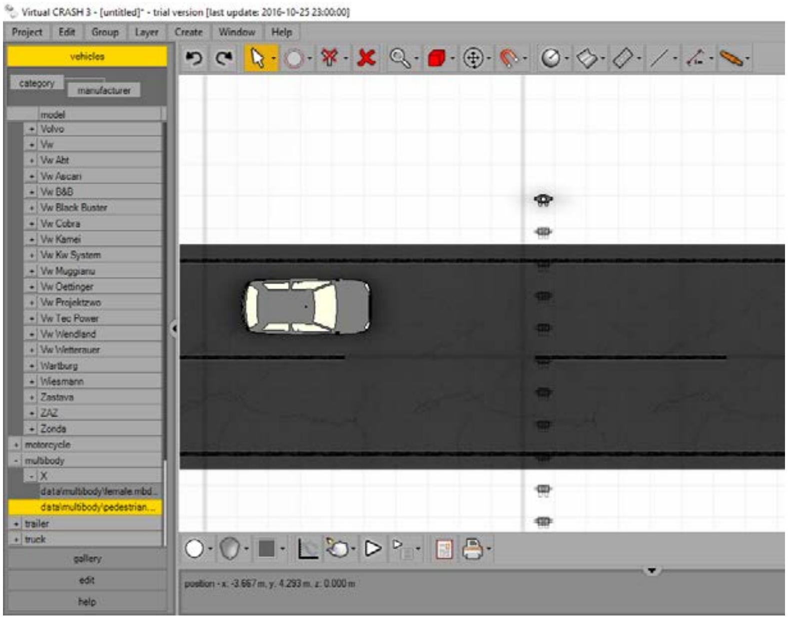


Fig. 2 Influence of speed on the throw distance for Rau/Otte dataset

4. MODELING AND SIMULATION USING VCRASH

In order to verify the theoretical statistical approaches presented, a model was created in VCrash software[8], consisting of a motor vehicle taken from the application database and a pedestrian.



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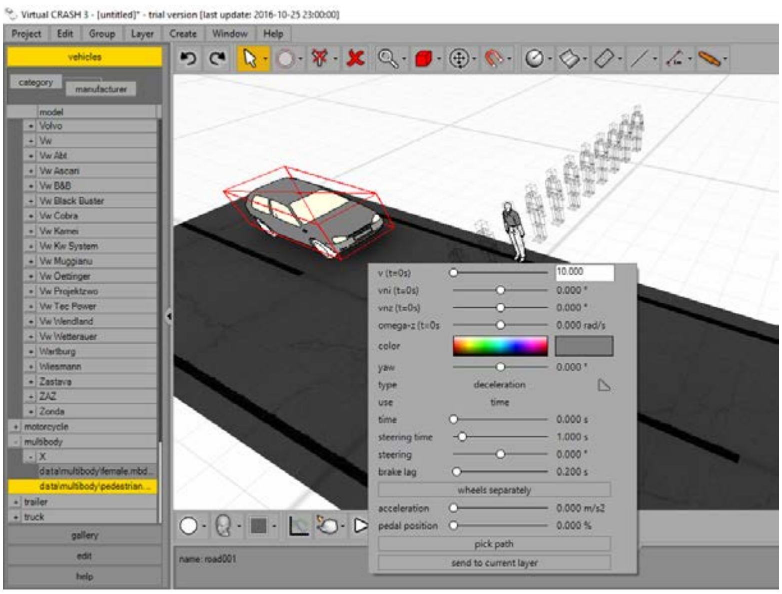
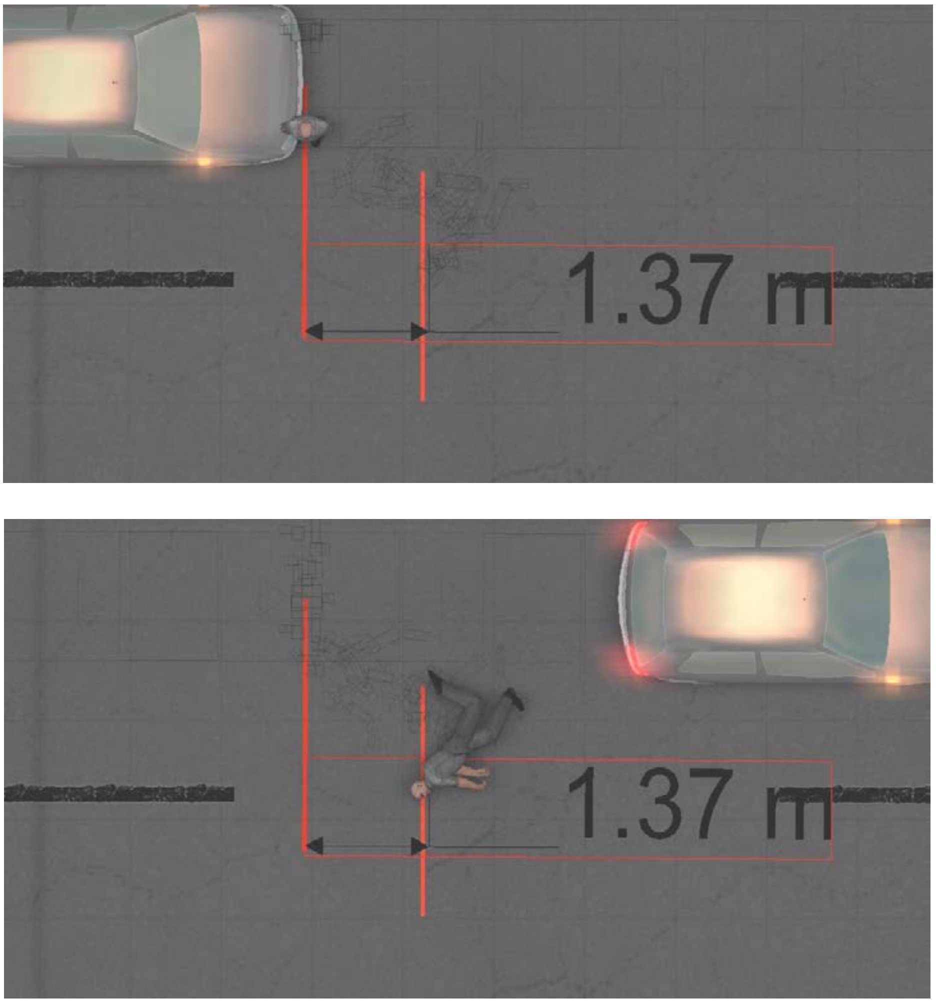


b

Fig. 3 Model of accident: a) 2D view; b) 3D view and vehicle speed setup

The first vehicle speed imposed was of 10 km/h. For the pedestrian a path perpendicular to the direction of the vehicle was setup, and a speed of 6 km/h, corresponding to an adult man moving normally, was defined. The starting position of the vehicle has been adjusted so that the impact occurs with the front center part of the bonnet.

The simulation was first run for the initial set speed of 10 km/h. Markers were added for the initial contact position and the final position of the pedestrian on the road, in form of red help lines. Using the "dimension line" tool of VCrash, the distance between the two points was measured. The distance measured was added to table 1.



a

b

Fig. 4 Details of the simulation for 10 km/h with measured distance
a – contact moment and marker; b - final position and marker

The speed of the vehicle was increased in steps of 10 km/h, until the speed of 100 km/h and the simulation was run for each step. The speed of the pedestrian was kept at 6 km/h and the car position was adjusted so that the impact occurs with the front center part of the vehicle. For each simulation the markers and measurements were taken using the same approach as for the initial speed of 10 km/h. Values were added to table 1.

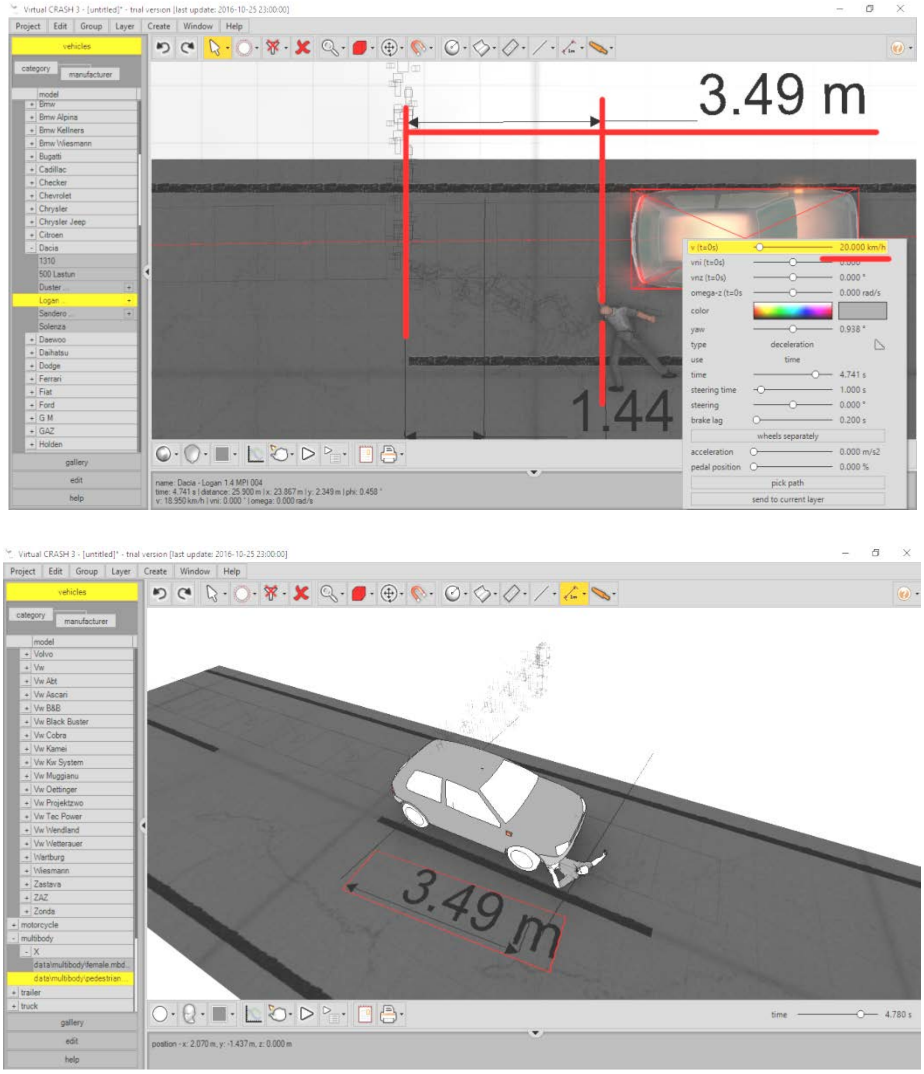


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Fig. 5 Details of the simulation for 20 km/h with measured distance
a – 2D view; b - 3D view

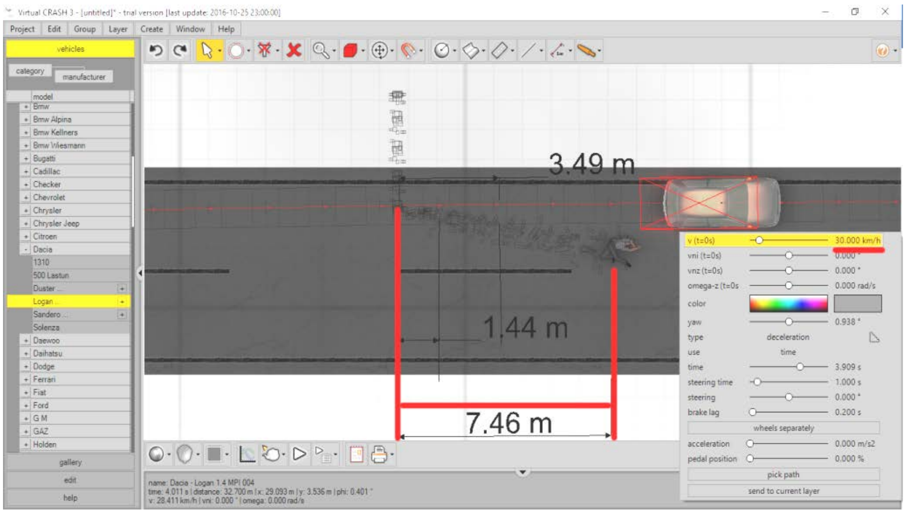

Fig. 6 Details of the simulation for 30 km/h with measured distance

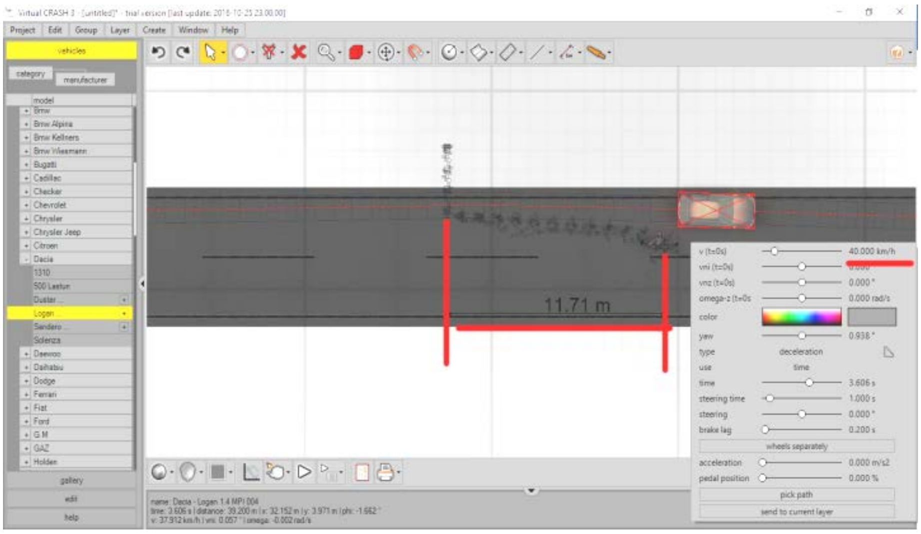

Fig. 7 Details of the simulation for 40 km/h with measured distance

In table 1, besides the measured value of S_p after VCrash simulations, the calculated values of the throw distance S_p, for the same speeds as simulation were introduced. Calculations were done using Rau/Otte formula (3).

Table 1 Results for $S_{p\ based}$ on simulation and calculation

W_a [km/h]	10	20	30	40	50	60	70	80	90	100
Simulated S_p	1.37	3.49	7.46	11.71	17.03	24.13	31.02	39.75	49.70	60.10
Calculated S_p	1.30	3.65	7.03	11.45	16.91	23.42	30.96	39.54	49.17	59.83

5. CONCLUSIONS

Computer modeling and simulation proves to be a good solution in accidents involving pedestrians, as the results obtained by simulation were very close to those obtained by calculation.

The differences are within margins acceptable for expertise.

By using dedicated software, the results can be presented multimedia 3D realistic animation so the visual impact is important. Simple to complex scenarios can be simulated, comparisons can be made for close values in order to better understand the phenomena and the actual accident dynamics. Changes to the scenarios and new variables can be quite easily introduced, and new results obtained in shorter time as compared to the classical methods.

The impact of rich visual presentation and simulation (in court, in front of police or insurance inspectors) is major, compared to the simple numbers and sketch-like drawings of classic approach, and based on these type of simulations the accident can even be better understood by general public. However, it is mandatory to perform calculations for validation purposes, in order to certify results given by simulation.

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