Comparative Analysis of Pedestrian Throwing Distance Following a Collision with a Vehicle

Oana Victoria Oţăt(✉), Ilie Dumitru, Dragoş Tutunea, and Lucian Matei

Faculty of Mechanical Engineering, University of Craiova, Craiova, Romania
oana.otat@edu.ucv.ro

Abstract. Starting from the statistical data in the field, according to which the most vulnerable road users are pedestrians, with the highest number of deaths, the present research deals with the problem of the impact between a vehicle and a pedestrian.

The main purpose of this study is to carry out a comparative analysis on the determination of kinematic parameters in the case of vehicle – pedestrian collision. An influencing factor on the value of the kinematic parameters and the pedestrian trajectory following the collision is represented by the front profile of the vehicle. For the virtual modeling of this impact, different frontal profiles of the vehicle were considered, but with the same characteristics of the pedestrian and the same impact speed.

The comparative analysis of the vehicle – pedestrian impact takes into account three different types of vehicle in terms of the frontal profile shape, namely: almost flat and vertical profile, high profile and low profile. The determination of the projection distances of the pedestrian following the impact was carried out by two methods.

Keywords: Collision · Pedestrian · Throwing Distance · Frontal Profile

1 Introduction

With the advent of the first means of transport and to this day, with the significant increase in the number of road vehicles, road traffic accidents have experienced a continuous evolution. The complexity of traffic accidents has generated and supported the development of new sciences and disciplines as well as the expansion and development of existing ones. While the number of deaths in road accidents has decreased by 43% over the past decade, the number of seriously injured people has decreased by only 36% [1].

Figure 1 shows the proportion of accidents resulting in fatalities by road type and by user type [2]. It is noticed that the largest proportion of the total number of deaths are those of drivers who were traveling on a rural road. As for pedestrians, more than 25% of road deaths occurred on motorways, and about 15% occurred on rural roads.

Figure 2 shows the distribution of deaths by road user category and country, with considerable differences being observed. In Romania, almost half (40%) of the number of deaths were related to pedestrians, 20% to drivers, 20% to passengers, about 7% to cyclists, while only 3% of the number of reported deaths were represented by motorcyclists [2].

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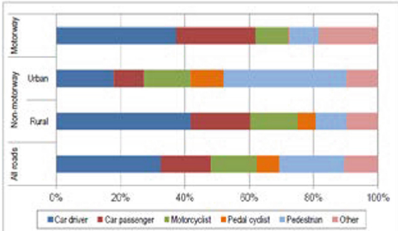


Fig. 1. Statistics of road accidents

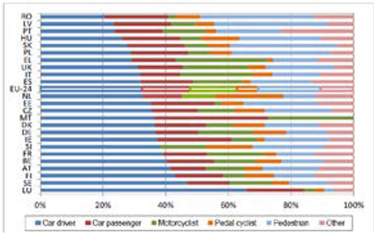


Fig. 2. Distribution of deaths by mode of transport

2 Factors of Influence on the Throwing Distance of the Pedestrian

The throwing distance of a pedestrian means the total sum of the distances measured longitudinally and travelled by the pedestrian, from the moment he came into contact with the vehicle, to the place where the pedestrian was at the final stage of the impact.

Thus, this amount is composed of the distance that the pedestrian was taken on the hood, the distance travelled by the pedestrian on the hood, the distance of throwing the pedestrian into the air and the distance of throwing the pedestrian on the carriageway.

The elements that show a high influence at the moment of impact with a pedestrian, on the throwing distance of the pedestrian are:

– vehicle impact speed,
– the shape of the vehicle frontal profile
– age, weight and height of the pedestrian

2.1 Vehicle Impact Speed

The speed of the vehicle at the moment of impact can be determined by reconstructing the trajectory of the victim's body after the collision by comparing it with its initial position at the moment of impact.

According to the literature, in the case of a vehicle-pedestrian accident, with a vehicle speed of up to 30 km/h, the pedestrian has a survival chance of over 80%, while in the case of a speed of 50 km/h, the pedestrian's survival chances are drastically reduced, decreasing to around 20%.

Fig. 3. Vehicle frontal profile

2.2 The Shape of the Vehicle Frontal Profile

The height of the vehicle and the shape of the body are two important factors in terms of the severity of pedestrian injury, as described in [3]. In recent years, there has been a tendency to decrease the height of the vehicle's centre of gravity and the height of the bonnet, leading to head injury by hitting the bonnet or windscreen of adult pedestrians. The degree of injury is reduced if the exterior of the cars is made without irregularities, without sharp edges.

Depending on the shape of the front profile, three categories are distinguished [4]:

a) front side almost flat and approximately vertical: in this case the point of impact is located above the pedestrian's center of gravity (hit point 1.05 m > from the ground).
b) high front; characterized by the fact that the point of impact is located above the knee, but not above the center of gravity (hit point located between 0.55 and 1.05 m from the ground).
c) low front: the impact point is located at or below the knee (impact point located below 0.55 m from the ground) (Fig. 3).

The trajectory of the victim's body can have two aspects [4]:

– the first aspect is the forward projection immediately after the impact.
– the second aspect is represented by throwing forward after the victim has previously been picked up on the hood.

3 Kinematic and Dynamic Study of Vehicle-Pedestrian Impact

The dynamics of the vehicle – pedestrian accident [5] requires the establishment of relationships describing the kinematics of the pedestrian as a result of the impact based on data and information, such as: height and weight of the pedestrian, height of the front bumper, height of the front hood, what the pedestrian was hit with, his position (face or back to the vehicle, moving, waiting), whether braking or not, maximum acceleration of the trunk and head of the pedestrian.

Specialized software in modeling various types of impact have been developed to simulate the movements of pre - and post-impact vehicles, as well as to determine the parameters of the collision.

One such specialized software is VirtualCrash, a state-of-the-art program for accident reconstruction. In the process of a collision between two vehicles, the impact phase in which the residual deformations occur has a very short duration, so at this stage vehicle rotations or twists are not possible. These movements occur after deformation of the bodies, so the position of the vehicles before the impact can be established precisely enough by superimposing the corresponding mark of the deformed parts.

3.1 Construction of the Vehicle-Pedestrian Impact Scenario

As the topic of the paper aims to carry out a comparative analysis on the throwing distance of the pedestrian following the impact with a vehicle, the virtual modeling of this impact will be carried out taking into account the three types of vehicle frontal profiles. The vehicle impact speed, as well as the pedestrian data will be the same in all three cases analyzed.

The first step in the construction of the scenario of a traffic accident is the design of infrastructure. For the present study - for each of the three cases analyzed, it is considered a stretch of roadway with a length of 50 m, with a single lane on the direction of traffic, with a width of 3.5 m and with 2 traffic directions.

3.2 Selection and Positioning of the Pedestrian Model

To perform the simulation, the male pedestrian model is used, having a height of 1.80 m, weight of 78 kg and is considered to be in the position *stepright*. For a male pedestrian aged 50 -60 years, the speed when walking fast is 6 km/h. The pedestrian will be positioned half the width of the pedestrian crossing and 2 m from the extreme right of the carriageway in the direction of travel of the vehicles.

3.3 Selection and Introduction of Vehicles

After the geometry of the carriageway of the accident site has been made, the second step follows namely the selection and introduction of the vehicles involved in the analyzed road accident. Virtual Crash software has a wide library of vehicle models and categories. Once inserted into the simulation, the software automatically generates all the data and dimensions of the respective vehicle.

The positioning of the vehicles will be done the same in all cases analyzed, namely: the front console of the vehicles will be located at the beginning of the pedestrian crossing, in the direction of travel of the vehicle. In the transversal plane, the vehicles shall be positioned at a distance of 1,00 m from the right front and right rear wheel to the right side of the carriageway in the direction of travel of the vehicle.

3.4 Setting Pre-collision Parameters

The model used by the program is a pre-calculation, when the input parameter is the vehicle speed prior to the collision, and from here the speed variations from the moment of separation are calculated.

The program uses the Kudlich-Sliba collision model [6], which makes it possible to calculate post-impact parameters using pre-impact data starting from defined input data

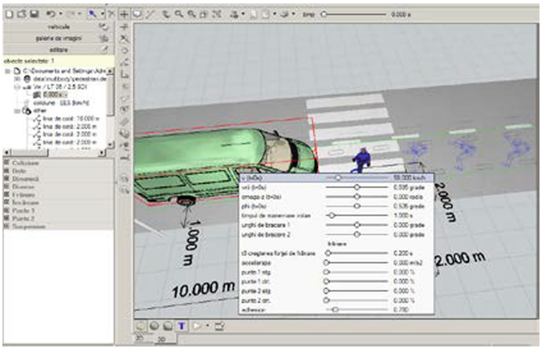


Fig. 4. Starting position and speed of the vehicle – case I

(mass, position). The method uses pre–collision speeds as input parameter. It takes into account the common displacement of the points of impact and calculates their velocities.

For all three vehicles considered the value of the initial parameters entered at the time of time t = 0: initial speed = 50 [km/h]; adhesion coefficient for dry road = 0.780 (Fig. 4).

4 Comparative Analysis of Pedestrian Throwing Distance

- Case I-vertical and almost flat frontal profile: In the situation of the impact between a pedestrian and a vehicle with a vertical and almost flat frontal profile, the trajectory of the victim's body consists of throwing in the forward direction immediately after the impact, without taking the victim on the hood, as happens in the other two cases.
- Case II-High frontal profile: In the case of an impact between a pedestrian and a vehicle with a high frontal profile, the trajectory of the victim's body consists of throwing in the forward direction after taking the victim on the hood, i.e. taking over at the level of the windshield of the vehicle.
- Case III-low frontal profile: In the case of an impact between a pedestrian and a vehicle with a high frontal profile, the trajectory of the victim's body consists of throwing in the forward direction after taking the victim on the hood, i.e. taking over at the level of the windshield of the vehicle (Table 1).

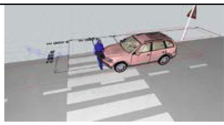
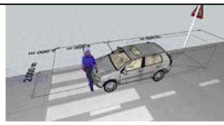
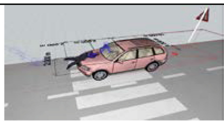
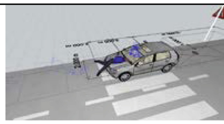
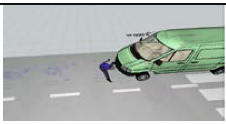
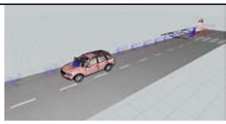
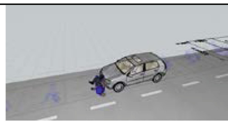
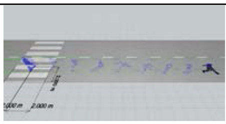
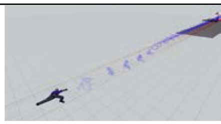
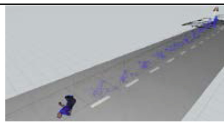
5 Determination of the Throwing Distance of the Pedestrian

5.1 Method I - Diagram Generating

The Virtual Crash program makes it possible to graphically illustrate the simulation. The diagrams can graphically illustrate the simulation according to time and distance, then speed, angular yaw speed, yaw angle and acceleration.

From the diagrams generated by the software, the total throwing distance of the pedestrian can be determined. For this, however, it is necessary to generate the variation of the speed diagram, depending on the space, for all three cases analyzed.

Table 1. Pedestrian trajectory for the three analyzed cases

	CASE I	CASE II	CASE III
Primary contact phase			
Pedestrian pickup and flight			
Pedestrian throwing phase			
Final phase of impact			

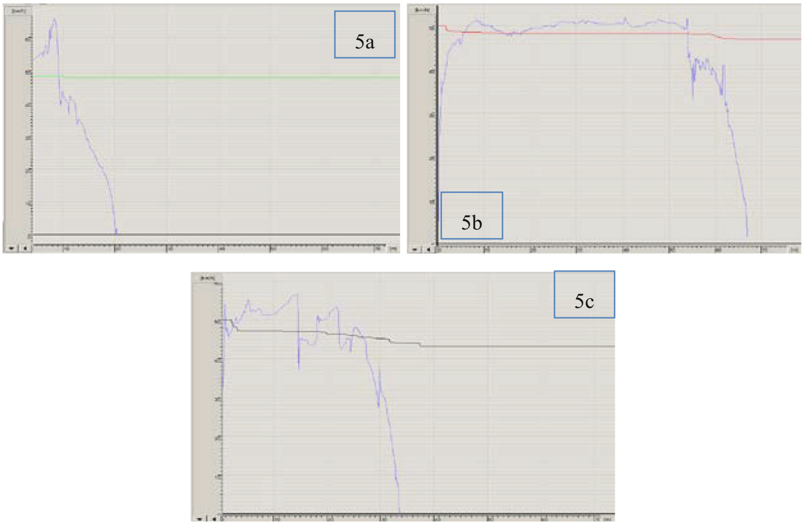


Fig. 5. Variation of velocity in travelled space - for vehicle and pedestrian-head component

From Fig. 5a, which represents the variation of velocity in travelled space – for vehicle 1 and pedestrian – the head component, it is observed that the total throwing distance of the pedestrian following the impact with the vehicle is approximately 20 m.

Table 2. Total pedestrian throwing distance

Case	Vehicle	Throwing distance [m]	Pickup on the hood
I	Vertical profile	20	No
II	High profile	66	Yes
III	Low profile	33	Yes

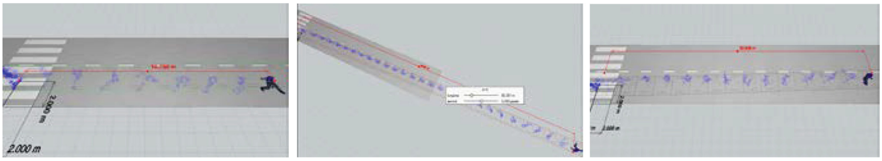


Fig. 6. Pedestrian throwing distance: a-case I, b-case II, c-case III

The variation velocity in travelled space – for vehicle 2 and the pedestrian head component, shows that the total throwing distance of the pedestrian following the impact with the vehicle is approximately 66 m – Fig. 5b. This distance also includes the space in which the pedestrian was carried on the engine hood of the vehicle.

As for the total throwing distance of the pedestrian for the case of impact with a vehicle with a low frontal profile, it is determined using the diagram in Fig. 5c, a total distance of approx. 33 m, which also includes the pedestrian carrying space on the engine hood of the vehicle.

Concluding the above, by determining the throwing distance of the pedestrian following the impact with the three types of vehicles analyzed (with different frontal profile), with the help of speed variation diagrams over time, the following values were obtained, according to Table 2.

5.2 Method II - Measurement of Pedestrian Throwing Distance

For the purpose of validating the distances obtained by means of speed variation diagrams according to the space traveled, the actual measurement method of the throwing distance shall also be used. This method is carried out through the option of creating the quota line directly in the working window of the program. The measured distances are shown in Figs. 6a, b, c.

The values obtained from the application of the second method for determining the throwing distance of the pedestrian are presented in Table 3.

Table 3. Pedestrian throwing distance

Case	Vehicle	Throwing distance [m]
I	Vertical profile	19.766
II	High profile	66, 251
III	Low profile	32.639

6 Conclusions

The main purpose of this study was to carry out a comparative analysis on the determination of kinematic parameters in the case of vehicle – pedestrian collision. An influencing factor on the value of the kinematic parameters and the pedestrian trajectory following the collision is represented by the front profile of the vehicle. The virtual modeling of this impact was done by considering different forms of the vehicle's front profile, but with the same pedestrian characteristics and the same impact speed. The three cases analyzed were:

- Case I-vertical and almost flat frontal profile: the trajectory of the victim's body consists of throwing in the forward direction immediately after the impact, without taking the victim on the hood
- Case II-high frontal profile: the trajectory of the victim's body consists of throwing in the forward direction after taking the victim on the hood, i.e. taking over at the level of the windshield of the vehicle
- Case III-low frontal profile: the trajectory of the victim's body consists of throwing in the forward direction after taking the victim on the hood, i.e. taking over at the level of the windshield of the vehicle

From the comparative analysis carried out, the following can be concluded:

- The vehicle – pedestrian impact comparative analysis took into account three different types of vehicle, in terms of the shape of the frontal profile, namely: almost flat vertical profile, high profile and low profile.
- The determination of the projection distances of the pedestrian following the impact was carried out by two methods. Comparing the obtained results it is found that the obtained values are very close, and are of: 20 m for case I, 66 m for case II, respectively 33 m for case III.
- As a result of the comparative analysis on the throwing distance of the pedestrian, it was shown that the shape of the frontal profile of the vehicle is an important factor, which can produce variations of this distance between 20–60 m, under the same driving conditions of the vehicle and with the same characteristics of the pedestrian.

From the obtained values it is found that the front profile shape of the vehicle represents one of the main factors in establishing the pedestrian's trajectory, but also in causing his injuries.

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