TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 59, Issue II, June, 2016

ASPECTS REGARDING THE NUMERICAL MODELING OF TRAFFIC INCIDENTS BETWEEN MOTORCYCLES AND PASSENGER CARS

Adrian TODORUŢ, Nicolae CORDOŞ, István BARABÁS, Monica BĂLCĂU

Abstract: *The paper evaluates from a physico-mathematical point of view the kinematic values of traffic incidents between motorcycles and passenger cars in their various stages. When evaluating the kinematic values of such incidents we take into account the parameters resulted from the primary search of the incident site. By reconstructing such incidents one aims to determine the velocity variation of the motorcyclist (man/woman - 5; 50; 95%), according to the distance covered by the motorcyclist from the initial impact until they reached the ground – the total distance of the impact, also taking into consideration the angle of the trajectory. In the situation of different impact angles of the motorcyclist until they reached the ground – the distance covered in air after impact as well as the total impact one, are determined according to the sliding distance covered on the type of soil that they have been projected on, by following the dependence between these kinematic values. The results obtained are in a graphic form and they offer the possibility of catching the various stages of the incident. The numerical model developed can be applied to solve a large number of cases of such motorcycle - passenger car traffic incidents in order to establish their dynamics when produced as well as their reconstruction.*
Key words: *passenger car, motorcyclist, traffic incident, kinematic values, numerical modeling*

1. INTRODUCTION

Traffic incidents generally involve two main factors [4-8, 15, 18, 19]: the vehicle and the people with their multiple qualities, as drivers, passengers, pedestrians, on a bicycle, on a motorcycle, etc.

In the case of motorcycle incidents, most of them and the most serious ones are the ones between motorcycles and passenger cars, which motivated researchers to focus on them more [10-13, 16, 20]. The consequences of a collision between a motorcycle and a passenger car depend on a series of factors, amongst which the most important ones are the type and the weight of the passenger car, the place, direction and side of the impact, road features, etc. Such collisions have the following common characteristics [5-8, 16, 19, 24]:

- the motorcycle low weight in comparison to the rest of traffic participants;
- motorcycle low adherence, which raises several situations in traffic;
- at the initial moment of the impact, the motorcyclist is part of the motorcycle, only to be separated by it as the collision develops;
- the motorcycle mass is smaller than the collisioned passenger car;
- the motorcyclist is usually cast, thus being removed from the motorcycle;
- an additional problem is appreciating the release angle of the motorcyclist (for real traffic incidents where we do not know the value of the launching/releasing angle, this can be assumed as being 45º);
- reduced physical protection of the motorcyclists, which increases their impact vulnerability;
- the evolution of the collision is influenced by the mass of the motorcyclists and the motorcycle, the impact is sustained only by the mass of the motorcycle: at first all the masses participate in the collision but then because the motorcyclists are disengaged, the impact is sustained only by the mass of the motorcycle; as a consequence, there is a

collision with a body whose mass is variable in time;

- the motorcycle-motorcyclist pair is more prone to imbalances;
- the motorcyclists need to focus more and for longer, thus being more prone to stress and mental fatigue;
- usually, the collision between a motorcycle and a passenger car takes place at relatively high speed, followed by the movement of the motorcycle/motorcyclist on a trajectory which can significantly influence the gravity of the incident;
- as a rule, the motorcyclist is exposed at three types of impacts: the initial impact with the passenger car, the secondary impact when they hit the road (ground) and a last impact (auxiliary) with objects or parts of the road.

The most frequent types of motorcycle - passenger car collisions are presented in figure 1 [5, 8-10, 20]. Figure 2 captures the distribution of various motorcycles incidents and figure 3 presents the distribution of the cast distances of motorcyclists according to each type of collision [8].

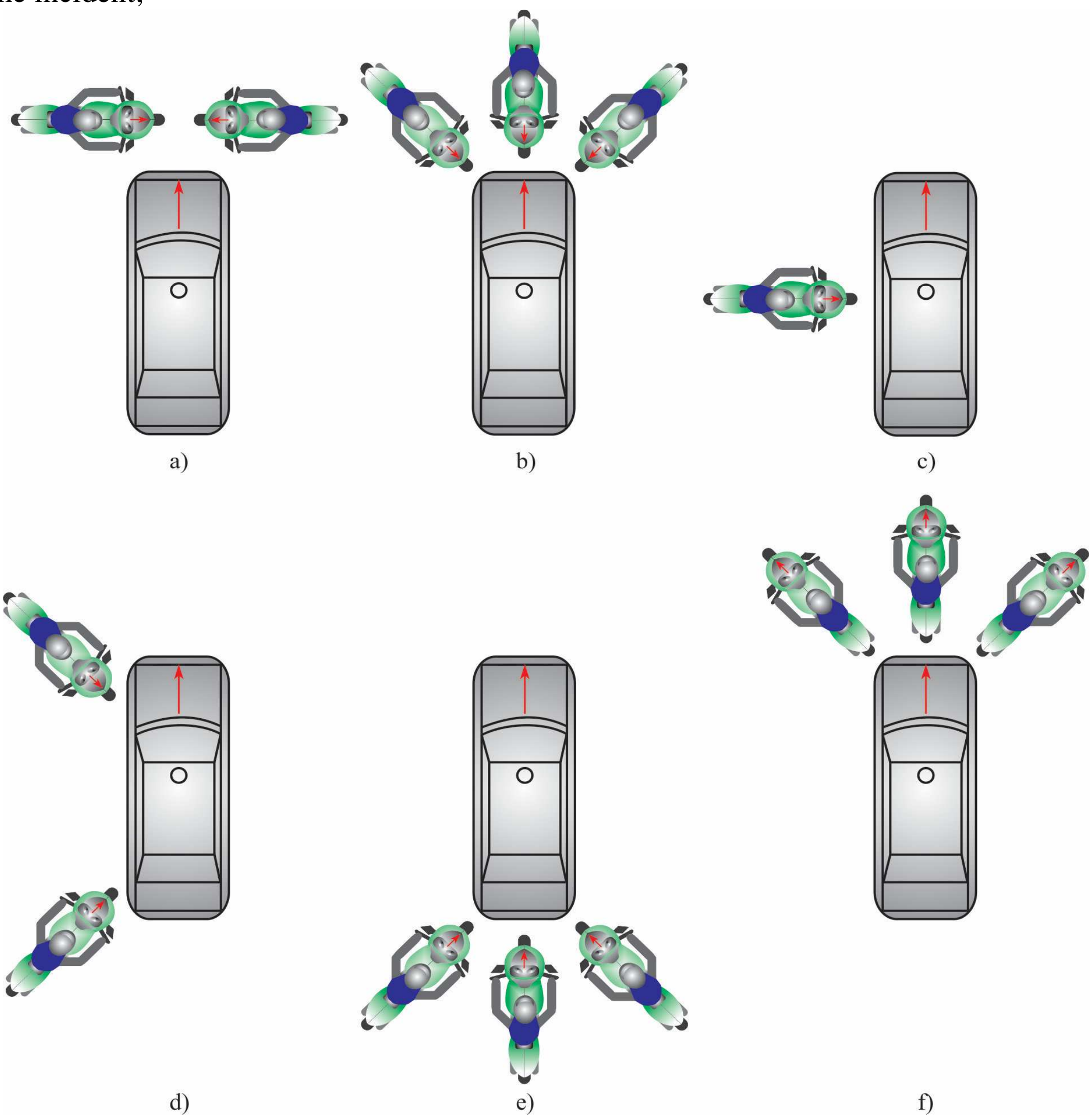

Fig. 1. Types of motorcycle - passenger car collision types. a) Type 1 collisions (90º±20º): frontal passenger car – lateral motorcycle; b) *Collisions type 2* (180º±70º): frontal passenger car – frontal motorcycle; c) *Collision type 3* (90º±20º): lateral passenger car – frontal motorcycle; d) *Collisions type 4:* passenger car in corners– frontal motorcycle; e) *Collisions type 5:* behind passenger car – frontal motorcycle; f) *Collisions type 6:* frontal passenger car – behind motorcycle.

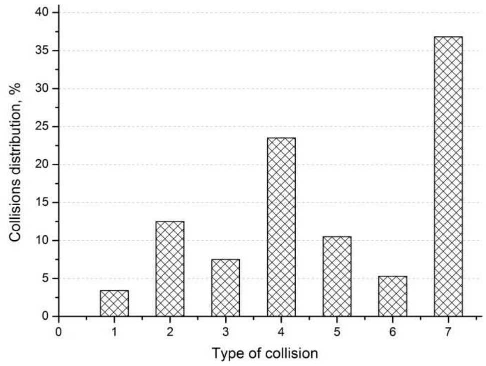

Fig. 2. Distribution of collision types in which motorcycles are involved. 1-6: types of motorcycle-passenger car collisions (see Fig. 1, a-f); 7: other types of collisions (with pedestrians, bicycle riders, motorcyclers, posts, trees outside the road, etc.).

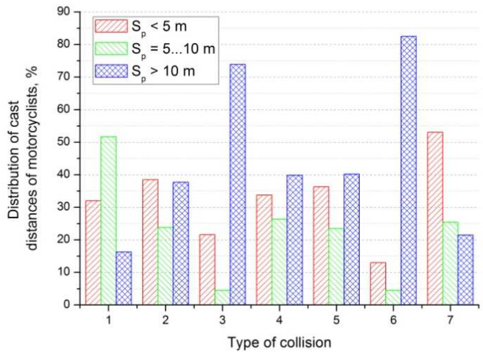

Fig. 3. Distribution of cast distances of motorcyclists according to the type of collision. 1-6: types of motorcycle - passenger car collisions (see Fig. 1, a-f); 7: other types of collisions (with pedestrians, bicycle riders, motorcyclists, posts, trees outside the road, etc.); S_p - the cast distance of the motorcyclist.

The statistical report of DRPCIV [22], regarding the national passenger car fleet, having as reference - 31.12.2015, shows that from the total national fleet, passenger cars represent 78% and motorcycles 0.38%. The document mentions that two powered wheelers (PTW - Powered Two Wheelers) represent 1.7% from the national fleet [22, 24].

The statistical report of DRPCIV [24], regarding the driving license categories at a national level, with a point of reference - 31.12.2014, reveals that the people having a driving license for two powered wheelers (AM, A1, A2, A) represent 20.3% (5.12% women, 15.18% men) of the total of people holding driving licenses, while the ones holding driving licenses for passenger cars, 98.74% (31.8% women, 66.94% men). The people with motorcycle licenses for heavy motorcycles, without power restrictions (A), represent 6.05% (0.2% women, 5.85% men) of the total of people holding driving licenses, 29.8% (0.99% women, 28.81% men) of the total of people holding driving licenses for powered two wheelers [23].

The national Road Department – IGPR – presented on 29.07.2015 [24], regarding the safety of vulnerable users, highlights the fact that of all severe traffic incidents, the drivers of powered two whellers are involved in 19% of cases, and in this category, the motorcyclists present the most severe consequences (62.63% of people were deceased and 53.78% severely injured in such). Evaluation of kinematic values in the case of the cast of the human body during traffic incidents in which motorcyclists, bicycle riders or pedestrians are involved are interesting continuously in various research [2, 3, 9-14, 16, 17, 20], and the literature captures the aspects of physical phenomena during such collisions [4-8, 15, 18, 19].

In order to evaluate the kinematic values of the motorcycle - passenger car collisions, this paper developed a numerical calculus using MathCAD, which takes into account the physical phenomena present in the stages consecutive of the collision, which take place in such incidents and which allow the user to obtain the aimed results with graphic interpretations.

In this respect, according to the input data (the variables taken into account – the parameters resulted from the primary research of the site), we aim to obtain results on: the relationship between the distance covered by the motorcyclist (male/female - 5; 50; 95%) from the moment they were cast until they hit the ground and the sliding distance on the ground they were cast, taking into account the angle of the trajectory; the variation of the distance covered by the motorcyclist from the moment they were cast until they reached the ground, respectively until they stopped on the groung, in the case of various angles of their trajectories, taking into account also the influence of the sliding space on the ground, the variation of the initial velocity according to the total distance cast, in the situation of various angle trajectories and various sliding distances.

2. THE METHOD OF NUMERICAL EVALUATION

To exemplify, we take into consideration type 3 of collision (see Fig. 1.c), where the velocities of the motorcycle and the passenger car have perpendicular directions (Fig. 4) [8]. In such circumstances, based on a calculus method developed in MathCAD, which offers results precise enough, one can determine the kinematic values of such a collision. In this respect, the center of gravity for the motorcyclist is considered to be above the impact point between the front and side wheels of the passenger car. This gives birth to the moment which slightly rotates the motorcycle around its front wheel, and in this time the motorcyclist is separated from the motorcycle and is cast over the hood of the passenger car on a trajectory that is initially inclined at an angle δ_0 (see Fig. 4), in relation to the plane of the ground. After they are separated from the motorcycle, the driver is cast through air at a distance S_{pa}, then when come in contact with the ground on which they slide until stopped at distance S_s, the energy of their body is dissipated to remove adherence, to tear the clothing, breaking bones, etc. The values and marks used in figure 4 and the numerical calculus model are presented in table 1.

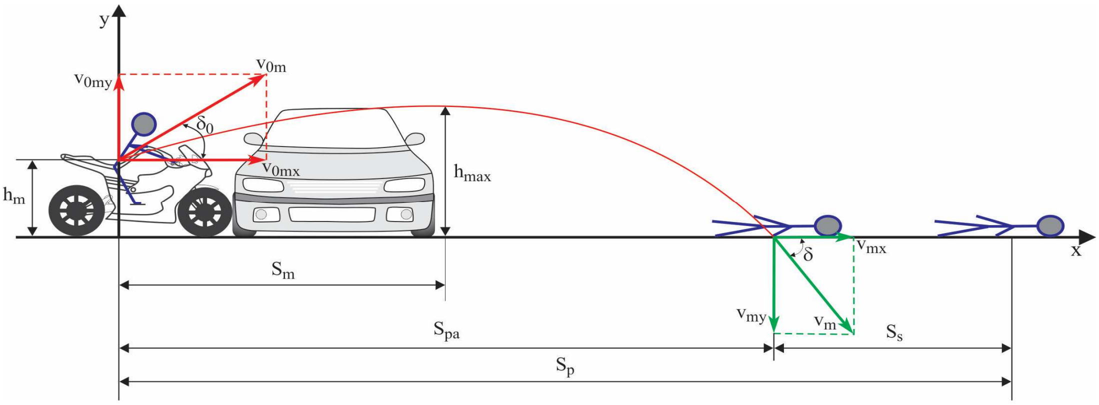

Fig. 4. Schematics of lateral collision between motorcycle and passenger car.

The numerical model uses a series of variables:

- i - characterises the initial inclination of the motorcyclist trajectory (i = 1…4; δ_{0_i} = 10°; 15°; 20°; 25°);
- j - characterises the height of the centre of gravity of the motorcyclist (h_{m_j}) [1, 18], (j = 1…6),
  - j = 1 - man, 5%, h_{m_1} = 0.976 m,
  - j = 2 - man, 50%, h_{m_2} = 1.015 m,
  - j = 3 - man, 95%, h_{m_3} = 1.056 m,
  - j = 4 - woman, 5%, h_{m_4} = 0.972 m,
  - j = 5 - woman, 50%, h_{m_5} = 1.004 m,
  - j = 6 - woman, 95%, h_{m_6} = 1.047 m;
    - man/woman 5% - the anthropometric sizes are smaller like in the case of 95% of adult male/female population;
    - man/woman 50% - the anthropometric sizes represent the average male/female population;
    - man/woman 95% - the anthropometric sizes are higher than in 95% of the male/female population;
- u - characterises space S_s, S_s, (u = 1…5; S_{s_u} = 3, 6, 9, 12, 15 m).

The equations [2-14, 16, 17, 19] of the mathematical model are defined in an orthogonal system with axis x along the plane of the road and on the direction and in the sense of the motorcyclist velocity and with axis y passing through the center of gravity of the motorcyclist in the position corresponding with the moment of impact of the motorcycle front wheel against the lateral side of the passenger car. This is the moment of reference for the time scale [8]. After impact, the motorcyclist has a horizontal movement with a constant speed and a vertical movement with a constant acceleration.

Table 1

Parameters used in the reconstructing of the motorcycle - passenger car traffic incidents

Value	Marking	U.M.
❑ the distance covered by the motorcyclist until reaching the maximum height	S_m	m
❑ the distance covered by the motorcyclist from the casting moment until they hit the ground (the casting distance through air)	S_{pa}	m
❑ the distance covered by the motorcyclist from the casting moment until they stopped on the ground (the total casting distance)	S_p	m
❑ the sliding distance, by a uniformly decelerated movement, of the motorcyclist on the ground that they were cast on	S_s	m
❑ the height of the center of gravity of the motorcyclist when the cast has started	h_m	m
❑ the maximum height of the trajectory of the motorcyclist	h_{max}	m
❑ time lapsed from the start of the cast until the maximum height is reached	t_m	s
❑ time lapsed from the start of the cast until the motorcyclist hit the ground	t_{pa}	s
❑ time corresponding to distance S_s covered by the motorcyclist, after they have reached the road and they roll and slide on the road slowing down (time corresponding to sliding over distance S_s)	t_s	s
❑ total time lapsed from the initial cast moment of the motorcyclist until they stopped on the ground	t_p	s
❑ the motorcyclist initial velocity	v_{0m}	m/s
❑ the horizontal initial velocity component of the motorcyclist	v_{0mx}	m/s
❑ the vertical initial velocity component of the motorcyclist	v_{0my}	m/s
❑ the vertical component of the motorcyclist velocity at a random moment and when they hit the ground (after time lapse t_{pa})	v_{my}	m/s
❑ the resulted velocity with which the body of the motorcyclist begins to move after it hits the ground (the motorcyclist velocity when they started to slide on the road)	v_m	m/s
❑ gravitational acceleration	g	m/s^2
❑ motorcyclist's mass	m_m	kg
❑ the angle between the initial trajectory of the motorcyclist and the road (the cast angle of the motorcyclist)	δ_0	degree
❑ the angle between the final trajectory of the motorcyclist and the road (the falling angle of the motorcyclist)	δ	degree
❑ global friction coefficient (forward resistance) of the body of the motorcyclist on the ground	f_m	-
❑ the ratio between the tangential momentum ($m_m \cdot v_{mx}$) and the vertical momentum ($m_m \cdot v_{my}$) of the forces developed when the motorcyclist's body hit the ground	μ	-

The vertical movement of the motorcyclist is characterised by the relation [2, 3, 8, 14]:

$$y = h_m + v_{0my} \cdot t - \frac{g \cdot t^2}{2} = h_m + (v_{0m} \cdot \sin\delta_0) \cdot t - \frac{g \cdot t^2}{2}, \quad (1)$$

where t is a random time.

The motorcyclist moves parallel with the road with a uniform movement according to the relation [2, 3, 8, 14]:

$$x = v_{0mx} \cdot t = (v_{0m} \cdot \cos\delta_0) \cdot t . \quad (2)$$

Taking into account the relations (1) and (2) we obtain [2, 8]:

$$y = h_m + x \cdot tg\delta_0 - \frac{g \cdot x^2}{2 \cdot v_{0m}^2 \cdot \cos^2\delta_0} . \quad (3)$$

After solving the equation (3) in connection to x results [8]:

$$x = \frac{v_{0m}^2 \cdot \sin\delta_0 \cdot \cos\delta_0}{g} + \sqrt{\frac{v_{0m}^4 \cdot \sin^2\delta_0 \cdot \cos^2\delta_0}{g^2} - (y - h_m) \cdot \frac{2 \cdot v_{0m}^2 \cdot \cos^2\delta_0}{g}} . \quad (4)$$

If the ground on which the motorcyclist is cast is at the same level with the road, then y = 0 and x = S_{pa}, therefore [4, 8, 14, 16, 17]:

$$S_{pa} = \frac{v_{0m}^2 \cdot \sin\delta_0 \cdot \cos\delta_0}{g} + \sqrt{\frac{v_{0m}^4 \cdot \sin^2\delta_0 \cdot \cos^2\delta_0}{g^2} + \frac{2 \cdot h_m \cdot v_{0m}^2 \cdot \cos^2\delta_0}{g}} . \quad (5)$$

Function y from the relation (3) allows a maximum for value of x = S_m, where $\frac{dy}{dx} = 0$ [8, 16]:

$$x = \frac{v_{0m}^2 \cdot \cos\delta_0 \cdot \sin\delta_0}{g} = S_m . \quad (6)$$

Taking into account relations (2), (3) and (6), we obtain time t_m and maximum height $y_{max} = h_{max}$, thus [8, 16, 17]:

$$t_m = \frac{v_{0m} \cdot \sin\delta_0}{g} ; \quad (7)$$

$$h_{max} = h_m + \frac{v_{0m}^2 \cdot \sin^2 \delta_0}{2 \cdot g}. \quad (8)$$

To determine t_{pa}, in relation (1) we must put the condition y = 0 and we obtain [2-4, 8, 16]:

$$t_{pa} = \frac{v_{0m} \cdot \sin \delta_0}{g} + \sqrt{\frac{v_{0m}^2 \cdot \sin^2 \delta_0}{g^2} + \frac{2 \cdot h_m}{g}}. \quad (9)$$

The vertical component v_{my} of the motorcyclist velocity at a random time t comes out from deriving the expression (1) [2-4, 8, 14, 17]:

$$dy/dt = v_{0m} \cdot \sin \delta_0 - g \cdot t = v_{my}. \quad (10)$$

At the moment of reaching the ground, that is after time lapse t_{pa}, the horizontal component v_{mx} of the motorcyclist velocity is the same with v_{0mx} ($v_{mx} = v_{0mx}$), and the horizontal component v_{my} of the motorcyclist velocity will be $v_{my} = v_{0m} \cdot \sin \delta_0 - g \cdot t_{pa}$. Thus, taking into account the relation (9), velocity v_{my} cand be expressed by the relation [8, 16]:

$$v_{my} = -\sqrt{v_{0m}^2 \cdot \sin^2 \delta_0 + 2 \cdot g \cdot h_m}. \quad (11)$$

The angle δ between the motorcyclist trajectory and the road can be determined according to the velocities v_{mx} and v_{my}, thus [8, 17]: și v_{my}, astfel [8, 17]: $\delta = \mathrm{arctg} \frac{|v_{my}|}{v_{mx}} \Rightarrow$

$$\delta = \mathrm{arctg} \frac{\sqrt{v_{0m}^2 \cdot \sin^2 \delta_0 + 2 \cdot g \cdot h_m}}{v_{0m} \cdot \cos \delta_0}. \quad (12)$$

The resulting velocity v_m, with which the body of the motorcyclist begins to move on the road after they have fallen on the ground, is determined taking into account the fact that the impact between the motorcyclist and the road is without rebound, and, according to the principle of momentum conservation ($m_m \cdot v_m = m_m \cdot v_{mx} + \mu \cdot m_m \cdot v_{my}$), we obtain the relation [2-4, 8, 17]:

$$v_m = v_{mx} + \mu \cdot v_{my}, \quad (13)$$

where $\mu = -f_m$ (μ is confounded with f_m).

After the fall, the motorcyclist rolls over and slides on the road in a slowing down movement, with a friction coefficient f_m, and eventually stops after covering a certain distance S_s, which is covered in time t_s. The friction coefficient f_m between the motorcyclist and the road is a drag coefficient [2-5, 8-14], because, apart from the friction itself with the road, there are also tumbles; a large part of estimating f_m is played by the energy losses due to clothing being torn, bones being broken, etc.

Taking into consideration relations (11), (13) and the value of v_{mx}, the resulting velocity v_m with which the motorcyclist body starts to move after its impact with the ground becomes [8, 16]:

$$v_m = v_{0m} \cdot \cos \delta_0 - \mu \cdot \sqrt{v_{0m}^2 \cdot \sin^2 \delta_0 + 2 \cdot g \cdot h_m}. \quad (14)$$

Sliding distance S_s on the ground and time t_s needed to cover this distance results from the conditions of a uniform decelerated movement of the motorcyclist [8, 16, 17]:

$$S_s = \frac{v_m^2}{2 \cdot g \cdot f_m}; \quad (15)$$

$$t_s = \frac{v_m}{g \cdot f_m}. \quad (16)$$

Total movement time t_p and total cast distance S_p of the motorcyclist are obtained according to the relations [8, 16]:

$$t_p = t_{pa} + t_s; \quad (17)$$

$$S_p = S_{pa} + S_s. \quad (18)$$

Generally, in the practice of tehnical expertise, there is the need to determine the velocity of the motorcycle, respectively the initial velocity with which the motorcyclist is cast, based on the incident site evidence [8]. Thus, according to the notations used, one can use the relations:

– if the distance S_s is known, taking into account the relation (14), adapted to the variables takent into account:

$$v_{0m_{i,j,u}} \cdot \cos \delta_{0_i} - \mu \cdot \sqrt{v_{0m_{i,j,u}}^2 \cdot \sin^2 \delta_{0_i} + 2 \cdot g \cdot h_{m_j}} - v_{m_u} = 0, \quad (19)$$

velocity v_{0m} can be determined as a solution to the equation:

$$v_{0m_{i,j,u}}^2 \cdot (\cos^2 \delta_{0_i} - \mu^2 \cdot \sin^2 \delta_{0_i}) - v_{0m_{i,j,u}} \cdot 2 \cdot v_{m_u} \cdot \cos \delta_{0_i} + (v_{m_u}^2 - 2 \cdot \mu^2 \cdot g \cdot h_{m_j}) = 0, \quad (20)$$

with the help of the relation [8]:

$$v_{0m_{i,j,u}} = \frac{v_{m_u} \cdot \cos \delta_{0_i}}{\cos^2 \delta_{0_i} - \mu^2 \cdot \sin^2 \delta_{0_i}} + \sqrt{\left(\frac{v_{m_u} \cdot \cos \delta_{0_i}}{\cos^2 \delta_{0_i} - \mu^2 \cdot \sin^2 \delta_{0_i}}\right)^2 - \frac{v_{m_u}^2 - 2 \cdot \mu^2 \cdot g \cdot h_{m_j}}{\cos^2 \delta_{0_i} - \mu^2 \cdot \sin^2 \delta_{0_i}}}, \quad (21)$$

In which velocity v_m is expressed according to distance S_s using relation [2-14, 17, 19]:

$$v_{m_u} = \sqrt{2 \cdot f_m \cdot g \cdot S_{s_u}}\ ; \qquad (22)$$

– if the distance S_{pa} is known, the velocity v_{0m} can be determined using the relation (5), adapted to the variables taken into account:

$$\sqrt{\left(\frac{v^2_{0m_{i,j,u}} \cdot \sin\delta_{0_i} \cdot \cos\delta_{0_i}}{g}\right)^2 + \frac{2 \cdot h_{m_j} \cdot v^2_{0m_{i,j,u}} \cdot \cos^2\delta_{0_i}}{g}} = S_{pa_{i,j,u}} - \frac{v^2_{0m_{i,j,u}} \cdot \sin\delta_{0_i} \cdot \cos\delta_{0_i}}{g}, \qquad (23)$$

transformed into a second degree equation with the form:

$$v^2_{0m_{i,j,u}} \cdot \left(2 \cdot \frac{\sin\delta_{0_i} \cdot \cos\delta_{0_i}}{g} \cdot S_{pa_{i,j,u}} + \frac{2 \cdot h_{m_j} \cdot \cos^2\delta_{0_i}}{g}\right) = S^2_{pa_{i,j,u}}, \qquad (24)$$

with the solution [4, 6, 8, 14]:

$$v_{0m_{i,j,u}} = \frac{S_{pa_{i,j,u}}}{\sqrt{\frac{\sin 2\delta_{0_i}}{g} \cdot S_{pa_{i,j,u}} + \frac{2 \cdot h_{m_j} \cdot \cos^2\delta_{0_i}}{g}}}; \qquad (25)$$

– if the distance S_p, is known, velocity v_{0m} can be calculated using the relation (18), where the relations (5), (14) and (15) are introduced:

$$\frac{v^2_{0m_{i,j,u}} \cdot \sin\delta_{0_i} \cdot \cos\delta_{0_i}}{g} + \sqrt{\left(\frac{v^2_{0m_{i,j,u}} \cdot \sin\delta_{0_i} \cdot \cos\delta_{0_i}}{g}\right)^2 + \frac{2 \cdot h_{m_j} \cdot v^2_{0m_{i,j,u}} \cdot \cos^2\delta_{0_i}}{g}} + \left\{\frac{v_{0m_{i,j,u}} \cdot \cos\delta_{0_i} - \mu \cdot \sqrt{v^2_{0m_{i,j,u}} \cdot \sin^2\delta_{0_i} + 2 \cdot g \cdot h_{m_j}}}{\sqrt{2 \cdot f_m \cdot g}}\right\}^2 - S_{p_{i,j,u}} = 0, \qquad (26)$$

and, after simplifications, we get the equation:

$$v^2_{0m_{i,j,u}} \cdot \frac{(\cos\delta_{0_i} + f_m \cdot \sin\delta_{0_i})^2}{2 \cdot f_m \cdot g} = S_{p_{i,j,u}} - \mu \cdot h_{m_j}, \qquad (27)$$

whose solution is [2, 3, 5, 9-14]:

$$v_{0m_{i,j,u}} = \frac{\sqrt{2 \cdot g \cdot f_m \cdot (S_{p_{i,j,u}} - \mu \cdot h_{m_j})}}{\cos\delta_{0_i} + f_m \cdot \sin\delta_{0_i}}. \qquad (28)$$

The total cast distance of the motorcyclist $S_{p_{i,j,u}}$ can be calculated according the variables considered (δ_{0_i}, h_{m_j} și S_{s_u}), using the relation (see Fig. 4):

$$S_{p_{i,j,u}} = S_{pa_{i,j,u}} + S_{s_u}. \qquad (29)$$

The cast distance of the motorcyclist through the air $S_{pa_{i,j,u}}$ can also be determined according the variables considered (δ_{0_i}, h_{m_j} și S_{s_u}), using the relations (5), (21) and (22) or relations (21), (22) and (25), from which we obtain a second degree equation with the form:

$$S^2_{pa_{i,j,u}} - \frac{4 \cdot f_m \cdot S_{s_u} \cdot \sin\delta_{0_i} \cdot \cos\delta_{0_i}}{\cos^2\delta_{0_i} - \mu^2 \cdot \sin^2\delta_{0_i}} \cdot \left[\cos\delta_{0_i} + \sqrt{\mu^2 \cdot \sin^2\delta_{0_i} + \frac{\mu \cdot h_{m_j}}{S_{s_u}} \cdot \left(\cos^2\delta_{0_i} - \mu^2 \cdot \sin^2\delta_{0_i}\right)}\right]^2 \cdot S_{pa_{i,j,u}} - \frac{4 \cdot h_m \cdot f_m \cdot S_{s_u} \cdot \cos^2\delta_{0_i}}{\cos^2\delta_{0_i} - \mu^2 \cdot \sin^2\delta_{0_i}} \cdot \left[\cos\delta_{0_i} + \sqrt{\mu^2 \cdot \sin^2\delta_{0_i} + \frac{\mu \cdot h_{m_j}}{S_{s_u}} \cdot \left(\cos^2\delta_{0_i} - \mu^2 \cdot \sin^2\delta_{0_i}\right)}\right]^2 = 0, \qquad (30)$$

whose solution is:

$$S_{pa_{i,j,u}} = \frac{2 \cdot f_m \cdot S_{s_u} \cdot \sin\delta_{0_i} \cdot \cos\delta_{0_i}}{\cos^2\delta_{0_i} - \mu^2 \cdot \sin^2\delta_{0_i}} \cdot \left[\cos\delta_{0_i} + \sqrt{\mu^2 \cdot \sin^2\delta_{0_i} + \frac{\mu \cdot h_{m_j}}{S_{s_u}} \cdot \left(\cos^2\delta_{0_i} - \mu^2 \cdot \sin^2\delta_{0_i}\right)}\right]^2 + \sqrt{\left\{\frac{2 \cdot f_m \cdot S_{s_u} \cdot \sin\delta_{0_i} \cdot \cos\delta_{0_i}}{\cos^2\delta_{0_i} - \mu^2 \cdot \sin^2\delta_{0_i}} \cdot \left[\cos\delta_{0_i} + \sqrt{\mu^2 \cdot \sin^2\delta_{0_i} + \frac{\mu \cdot h_{m_j}}{S_{s_u}} \cdot \left(\cos^2\delta_{0_i} - \mu^2 \cdot \sin^2\delta_{0_i}\right)}\right]^2\right\}^2 + \frac{4 \cdot h_m \cdot f_m \cdot S_{s_u} \cdot \cos^2\delta_{0_i}}{\cos^2\delta_{0_i} - \mu^2 \cdot \sin^2\delta_{0_i}} \cdot \left[\cos\delta_{0_i} + \sqrt{\mu^2 \cdot \sin^2\delta_{0_i} + \frac{\mu \cdot h_{m_j}}{S_{s_u}} \cdot \left(\cos^2\delta_{0_i} - \mu^2 \cdot \sin^2\delta_{0_i}\right)}\right]^2}. \qquad (31)$$

3. RESULTS OBTAINED

Based on the calculus method we obtain results with a graphic interpretation of the kinematic values that characterise the motorcycle - passenger car type collisions. To exemplify, in the numerical calculus model, apart from the mentioned variables (δ_{0_i}, h_{m_j} and S_{s_u}) we also took into account the following data input: $f_m = 0.8$; $\mu = 0.8$; the height of the motorcycle saddle [21], cca. 0.8 m.

Based on the input data and taking into account the physical phenomena from the stages consecutive the motorcycle - passenger car collision (see Fig. 4) and using the numerical calculus model developed in MathCAD, we obtained the results regarding the connection between the distance covered by the motorcyclist from the moment of the cast until they hit the ground (Fig. 5, Fig. 6), respectively the total cast distance of the motorcyclist (Fig. 7, Fig. 8) and their sliding distance on the ground they have been cast, taking into account the inclination angle of their trajectory. Also, taking into account the input data (δ_{0_i}, h_{m_j} and S_{s_u}), we can determine the velocity variation of the motorcyclist according to the total cast distance (Fig. 9, Fig. 10, Fig. 11, Table 2), according to various cast angles of the motorcyclist and various sliding distances.

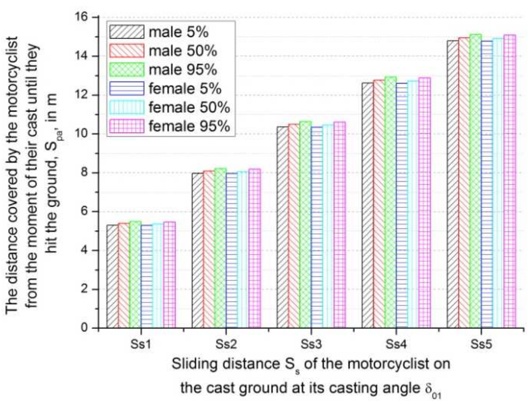

Fig. 5. The relation between the distance covered by the motorcyclist from the moment of their cast until they hit the ground ($S_{pa_{i,j,u}}$) and the sliding distance on the ground they have been cast on (S_{s_u}), for inclination trajectory angle (δ_{0_1}).

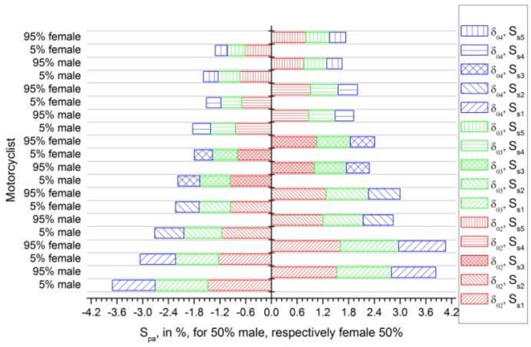

Fig. 6. Variation in the distance covered by the motorcyclist from the moment they were cast until they hit the ground, in %, for various trajectories inclinations ($\delta_{0_{2,3,4}}$), taking as comparison basis a male motorcyclist 50%, respectively female 50%, taking into account the influence of the sliding space on the ground they have been cast ($S_{s_{1...5}}$).

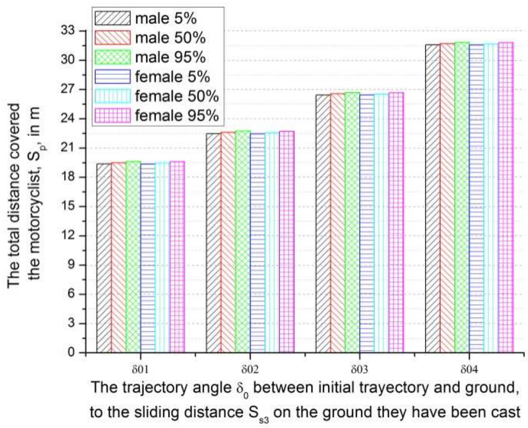

Fig. 7. Variation in the distance covered by the motorcyclist from the moment they were cast until they stopped on the ground ($S_{p_{i,j,3}}$) according to the trajectory angle (δ_{0_i}), to the sliding distance on the ground they have been cast (S_{s_3}).

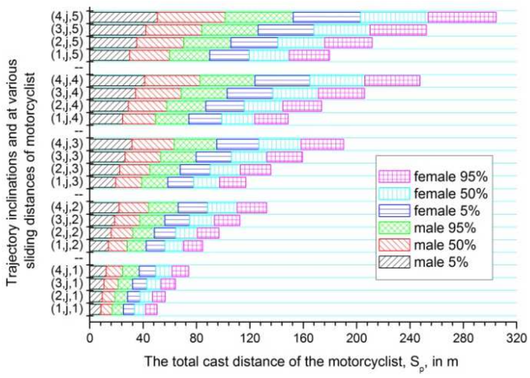

Fig. 8. The total cast distance of the motorcyclist ($S_{p_{i,j,u}}$), at various trajectory inclinations (δ_{0_i}) and at various sliding distances (S_{s_u}).

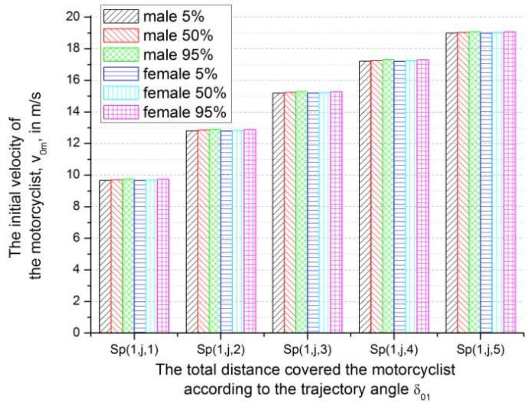

Fig. 9. Variation of the initial velocity of the motorcyclist ($v_{0m_{1,j,u}}$) according to the distance covered from the cast moment until they stopped on the ground ($S_{p_{1,j,u}}$), at the trajectory angle (δ_{0_1}) and the sliding distance (S_{s_u}).

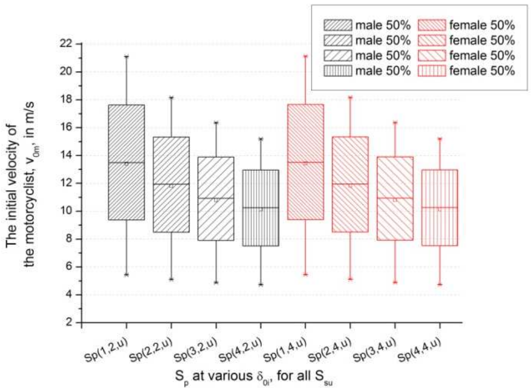

Fig. 10. The initial velocity of the motorcyclist (male 50%, respectively female 50%), for the various total cast distances ($S_{p_{i,2,u}}$, $S_{p_{i,4,u}}$), at various trajectory angles (δ_{0_i}) and all sliding distances (S_{s_u}).

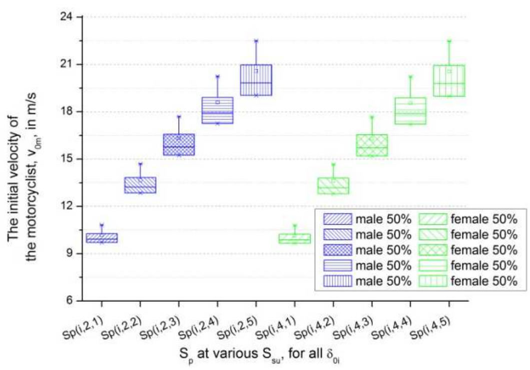

Fig. 11. The initial velocity of the motorcyclist (male 50%, respectively female 50%), for the various total cast distances ($S_{p_{i,2,u}}$, $S_{p_{i,4,u}}$), at all sliding distances (S_{s_u}) and at all trajectory angles (δ_{0_i}).

The results obtrained (graphic - Fig. 5…11 and in table form - Table 2) also take into account the influence of the height of the centre of gravity (h_{m_j}) of each motorcyclist included in the study, thus being able to compare and evaluate the kinematic values that characterise such a collision.

The results obtained after applying the numerical calculus model developed enable their user a graphic representation (see Fig. 5…11), thus allowing a comparative analysis of all the situations taken into account. Thus, one can focus on the situations most frequently met in such traffic incidents, which can be then compared to other specific situations encountered in the practice of traffic incident expertise.

4. CONCLUSIONS

In the case of mathematical modelling, the circumstances of a traffic incident can be examined using the modelling described by the mechanical theory and mathematical methods, with results that can be influenced by the input data, so that their effect can be researched easily. If one knows enough information about an incident between a motorcycle and a passenger car, one can establish a series of parameters using the calculus model, which can be interesting for solving the traffic incident.

The developed numerical model aiming to evaluate the kinematic values characterising traffic incidents of motorcycle - passenger car type, allows the user to change the input data, to take into account other impact conditions, respectively to obtain results with a graphic interpretation. This model can be applied for solving cases of motorcycle - passenger car traffic incidents in order to establish the dynamics of such incidents and the influence of various factors that contribute to their evolution.

Taking into account the variables considered, the results could be captured in a comparative manner, according to the motorcyclists considered, the inclination of their trajectory, etc. Aside from the results presented, the calculus algorithm allows the user to obtain other results as well, such as:

– time lapsed from the start of the cast until the maximum height is reached;

- the maximum height of the trajectory of the motorcyclist;
- the distance covered by the motorcyclist until reaching the maximum height;
- the angle between the motorcyclist trajectory and the road, at the moment of hitting the ground;
- time lapsed from the start of the cast until the motorcyclist hit the ground;
- time corresponding to the motorcyclist sliding, after hitting the ground;
- total time lapsed from the initial cast moment of the motorcyclist until they stopped on the ground;
- total time lapsed from the initial cast moment of the motorcyclist until they stopped on the ground;
- the variation of the initial velocity of the motorcyclist according to the distance covered by the motorcyclist from the cast until they hit the ground, at various trajectory angles and for various sliding distances;
- the variation of the initial velocity of the motorcyclist according to the sliding distance, for various trajectory angles etc.

Table 2

Variation in the initial velocity of the motorcyclist v_{0m}, in %, according to the total cast distance $S_{p_{i,j,u}}$ in the situation of various trajectory inclinations (δ_{0_i}) and various sliding distances (S_{s_u}), taking as comparative basis a male motorcyclist 50%, respectively female motorcyclist 50%

Motorcyclist / $S_{p_{i,j,u}}$	male		female	
	5%	95%	5%	95%
$S_{p_{1,j,1}}$	-0.412031	+0.422332	-0.340311	+0.443436
$S_{p_{1,j,2}}$	-0.326874	+0.342439	-0.272649	+0.358339
$S_{p_{1,j,3}}$	-0.282134	+0.288695	-0.229825	+0.308622
$S_{p_{1,j,4}}$	-0.243394	+0.260779	-0.202969	+0.272559
$S_{p_{1,j,5}}$	-0.225912	+0.225912	-0.183997	+0.241825
$S_{p_{2,j,1}}$	-0.373285	+0.373285	-0.303000	+0.404000
$S_{p_{2,j,2}}$	-0.279752	+0.294874	-0.234564	+0.302663
$S_{p_{2,j,3}}$	-0.228267	+0.240949	-0.190343	+0.253791
$S_{p_{2,j,4}}$	-0.195258	+0.200837	-0.161876	+0.217695
$S_{p_{2,j,5}}$	-0.171457	+0.176500	-0.136226	+0.186680
$S_{p_{3,j,1}}$	-0.321324	+0.331061	-0.272878	+0.341097
$S_{p_{3,j,2}}$	-0.231448	+0.238681	-0.188174	+0.253311
$S_{p_{3,j,3}}$	-0.181017	+0.187051	-0.144893	+0.199227
$S_{p_{3,j,4}}$	-0.148125	+0.158705	-0.121725	+0.164065
$S_{p_{3,j,5}}$	-0.128780	+0.133550	-0.104967	+0.138365
$S_{p_{4,j,1}}$	-0.268121	+0.277367	-0.222058	+0.296077
$S_{p_{4,j,2}}$	-0.183761	+0.183761	-0.149813	+0.197480
$S_{p_{4,j,3}}$	-0.141267	+0.141267	-0.113058	+0.152629
$S_{p_{4,j,4}}$	-0.113597	+0.113597	-0.088933	+0.123518

$S_{p_{4,j,5}}$	-0.093317	+0.093317	-0.075562	+0.102231

The numerical model can also be adapted for the situations in which, knowing the cast velocities of the motorcyclists, one wants to find out the values of the other kinematic parameters that characterise such a traffic incident (cast and sliding distances, cast angles, etc.). In addition, the calculus model can be developed for the situation when the road has various longitudinal and/or transversal inclinations.

Avoiding such incidents can be accomplished if the motorcyclists use more caution in traffic, if they adapt the speed to the travel conditions, if they take more precautions when changing the direction, etc. Any traffic incident can be avoided by complying with the strict traffic rules and by constant attention paid when being part of the traffic.

5. REFERENCES

[1] Ahlstrom, V.; Longo, K., *Human Factors Design Standard (HF-STD-001)*, Atlantic City International Airport, NJ: Federal Aviation Administration William J. Hughes Technical Center, 2003 (amended/updated 2009), http://hf.tc.faa. gov/hfds/download.htm.

[2] Batista, M., *A Simple Throw Model for Frontal Vehicle-Pedestrian Collisions*, Promet - Traffic&Transportation, Vol. 20, 2008, No. 6, 357-368, http://www.fpz.unizg.hr/traffic/index.php/PROMTT/article/viewFile/1020/867.

[3] Bogdanović, L.; Batista, M., *The Throw Model for Vehicle/Pedestrian Collisions including Road Gradient*, Proceedings, 8th International Conference on Traffic Science (ICTS 2004), Nova Gorica, Slovenija, 11.-12. November 2004, http://s3.amazonaws.com/zanran_storage/www.fpp.edu/ContentPages/43384709.pdf.

[4] Brach, Raymond M.; Brach, R. Matthew, *Vehicle Accident Analysis and Reconstruction Methods, Second Edition*. Warrendale, PA, SAE International, 2011.

[5] Cristea, D., *Abordarea accidentelor rutiere*. Piteşti, Editura Universităţii din Piteşti, 2009.

[6] Franck, H.; Franck, D., *Mathematical Methods for Accident Reconstruction A Forensic Engineering Perspective*. CRC Press, Taylor & Francis Group, 2010.

[7] Gaiginschi, R.; Filip, I., *Expertiza tehnică a accidentelor rutiere.* București, Editura Tenică, 2002.

[8] Gaiginschi, R., *Reconstrucția și expertiza accidentelor rutiere.* București, Editura Tehnică, 2009.

[9] Otte, D., *Use of Throw Distances of Pedestrians and Bicyclists as Part of a Scientific Accident Reconstruction Method*, SAE Technical Paper 2004-01-1216, 2004, doi:10.4271/2004-01-1216.

[10] Otte, D., *Technical Parameters for Determination of Impact Speed for Motorcycle Accidents and the Importance of Relative Speed on Injury Severity*, SAE Technical Paper 2006-01-1562, 2006, doi:10.4271/2006-01-1562.

[11] Rich, A.S., *Estimating Vault Distance and Speed after Motorcycle or Bicycle Ejection*, NJAAR, The Newsletter for Accident Reconstructionists, Vol. 3 No. 2, 1997. http://www.tarorigin.com/art/Arich/.

[12] Searle, J. and Searle, A., *The Trajectories of Pedestrians, Motorcycles, Motorcyclists, etc., Following a Road Accident*, SAE Technical Paper 831622, 1983, doi:10.4271/831622.

[13] Searle, J., *The Physics of Throw Distance in Accident Reconstruction*, SAE Technical Paper 930659, 1993, doi:10.4271/930659.

[14] Stevenson, T.J., *Simulation of Vehicle-Pedestrian Interaction,* Thesis for the Degree of Doctor of Philosophy in Engineering in the University of Canterbury, 2006, http://ir.canterbury.ac. nz/handle/10092/1180.

[15] Todoruț, A., *Dinamica accidentelor de circulație.* Cluj-Napoca, Editura U.T. PRESS, 2008.

[16] Todoruţ, A.; Barabás, I.; Brânzaş, P.; Gavrilaş, C.A. *Reconstrucţia accidentelor rutiere motocicletă-automobil.* În: Ştiinţă şi Inginerie, Vol. 17, pg. 135-144. Bucureşti, Editura AGIR, 2010, ISSN 2067-7138, e-ISSN 2359-828X.

[17] Todoruţ, A.; Cordoş, N.; Barabás, I.; Bălcău, Monica. *The evaluation of kinematic measures which characterize the vehicle-pedestrian accidents*. Cluj-Napoca, Buletinul Ştiinţific al UTC-N, *Acta Technica Napocensis*, Series: *Applied Mathematics, Mechanics, and Engineering,* Vol. 58, Issue I, March, 2015, pg. 31-40, Editura U.T.PRESS, ISSN 1221-

5872, http://www.atna-mam. utcluj.ro/index.php/Acta/article/view/513.

[18] Todoruţ, I.-A.; Barabás, I.; Burnete, N., *Siguranţa autovehiculelor şi securitatea în transporturi rutiere***.** Cluj-Napoca, Editura U.T.PRESS, 2012.

[19] Van Kirk, Donald J., *Vehicular accident investigation and reconstruction*. CRC Press LLC, 2001.

[20] Whyte, T.; Gibson, T.; Brown, J.; Milthorpe, B.; Eager, D., *Mechanisms of head and neck injuries sustained by helmeted motorcyclists in NSW, Australia.* Paper Number 15-0332, http://www-esv.nhtsa.dot.gov/Proceedings/ 24/files/24ESV-000332.PDF.

[21] *** *Motoflash - Compară motocicletele noi, Specificații tehnice*. http://www. motoflash.ro/moto/compare (accessed on 02/02/2016).

[22] *** *Parc auto 2015*, *Data de referință - 31/12/2015.* DRPCIV - Directia Regim Permise de Conducere si Inmatriculare a Vehiculelor, Ministerul Afacerilor Interne, http://www.drpciv.ro/info-portal/displayStatistics.do (accessed on 09/02/2016).

[23] *** *Raport statistic categorii permise de conducere, Data de referință - 31.12.2014.* DRPCIV - Directia Regim Permise de Conducere si Inmatriculare a Vehiculelor, Ministerul Afacerilor Interne, http://www.drpciv.ro/info-portal/displayStatistics.do (accessed on 09/02/2016).

[24] *** *Siguranța utilizatorilor vulnerabili.* Inspectoratul General al Poliției Române, Direcția Rutieră, 2015. http://ec.europa.eu/transport/road_safety /pdf/2015_round_tables/politei_romane_vru. pdf (accessed on 09/02/2016).

ASPECTE CU PRIVIRE LA MODELAREA NUMERICĂ A ACCIDENTELOR RUTIERE MOTOCICLETĂ-AUTOTURISM

Rezumat: În lucrare se evaluează, din punct de vedere fizico-matematic, mărimile cinematice ale accidentelor rutiere motocicletă-autoturism, în diferite etape ale acestora. La evaluarea mărimilor cinematice care caracterizează asemenea accidente se ține seama de parametrii rezultați din cercetarea primară a locului faptei. Prin reconstituirea unor asemenea accidente se caută să se determine variația vitezei motociclistului (bărbat/femeie - 5; 50; 95%), în funcție de distanța parcursă de motociclist de la începerea proiectării până la oprirea pe sol - distanța totală de proiectare, ținând seama și de unghiul de înclinare a traiectoriei lui. În situația diferitelor unghiuri de lansare a motociclistului, atât distanța parcursă de motociclist din momentul începerii proiectării până la căderea pe sol - distanţa de proiectare prin aer, cât și cea totală de proiectare, se determină în funcție de distanța de alunecare a acestuia pe terenul pe care a fost proiectat, urmărind dependența dintre aceste mărimi cinematice. Rezultatele obținute sunt sub formă grafică și oferă posibilitatea surprinderii diverselor etape ale accidentului. Modelul numeric dezvoltat poate fi aplicat la soluționarea unui număr mare de cazuri de accidente rutiere, de tip motocicletă-autoturism, pentru a stabili dinamica producerii acestora, respectiv reconstituirea lor.

Adrian TODORUȚ, PhD. Eng., Associate Professor, Technical University of Cluj-Napoca, Faculty of Mechanical Engineering, Department of Automotive Engineering and Transports, Romania, adrian.todorut@auto.utcluj.ro, Office Phone 0264 401 674.

Nicolae CORDOȘ, PhD. Eng., Lecturer, Technical University of Cluj-Napoca, Faculty of Mechanical Engineering, Department of Automotive Engineering and Transports, Romania, Nicolae.Cordos@auto.utcluj.ro, Office Phone 0264 202 790.

István BARABÁS, PhD. Eng., Professor, Technical University of Cluj-Napoca, Faculty of Mechanical Engineering, Department of Automotive Engineering and Transports, Romania, a istvan.barabas@auto.utcluj.ro, Office Phone 0264 401 674.

Monica BĂLCĂU, PhD. Eng., Lecturer, Technical University of Cluj-Napoca, Faculty of Mechanical Engineering, Department of Automotive Engineering and Transports, Romania, monica.balcau@auto.utcluj.ro, Office Phone 0264 401 610.