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INVESTIGATING TRAFFIC ACCIDENTS: A COLLISION OF TWO MOTOR VEHICLES

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Abstract. Traffic safety may be ensured by normal operation of all elements of the system, including the driver, a motor vehicle and transportation medium. Insufficient safety of some particular elements of this system (the lack of discipline of the participants of traffic, poor technical state of a motor vehicle or road, etc.) are the main causes of traffic accidents. Statistical data on traffic accidents in 2000–2009 in Lithuania is presented. Collisions of motor vehicles in 2009 make one of the largest proportion of all traffic accidents – 33.4%. In 2009 drivers, were the main traffic accident perpetrators – 73.6%. The paper considers some major aspects of motor vehicle collision simulation based on the application of PC-CRASH software, allowing researchers to analyze the changes in the direction of motor vehicle motion in the case of a collision and the influencing factors. This type of traffic accident simulation consists in studying the circumstances of collision, reconstructing the processes, calculating the pre-impact speed of motor vehicles and determining various parameters of motor vehicles' movement at different stages of traffic accident development.

Keywords: road traffic, traffic accident, traffic safety, motor vehicle, collision, simulation, PC-CRASH.

1. Introduction

Road traffic embraces social relations associated with transportation of goods and passengers by motor vehicles or other means of transport.

Traffic safety embraces a number of measures aimed at ensuring safety of all participants of road traffic.

Ensuring traffic safety and safe use of motor vehicles refer to global problems faced by humanity.

The first traffic accident, a collision of a motor vehicle and a pedestrian, was recorded as early as in 1896, i. e. ten year after an automobile had been invented. In 1899, a man was killed in the traffic accident. Since then, the number of traffic accidents has been continually growing and causing a lot of troubles.

Specialists observed that, over the period of 114 years, all traffic accidents, including those involving the pedestrians, had become the matter of great concern to people all over the world. The statistics of the United Nations confirms this. According to the data provided by the above organization, the casualties of traffic accidents make 1.2 million people per year, while 50 million are injured. Moreover, traffic accidents make a major cause of young people's death at the age from 10 to 24 years. Only in Europe, about 350 people a day, or more than 127 thous. people a year, perish in traffic accidents. This makes the population of a middle-size town. In addition, 2.3 million people are injured or become handicapped due to traffic accidents. In general, the victims of traffic accidents make about a third of all casualties caused by accidents in the world.

Traffic safety may be ensured by normal operation of all elements of the system, including the driver, a motor vehicle and transportation medium. Insufficient safety of some particular elements of this system (the lack of discipline of the participants of traffic, poor technical state of a motor vehicle or road etc.) are the main causes of traffic accidents.

Traffic safety largely depends on motor vehicles, traffic participants and road infrastructure (Antov *et al.* 2009; Beljatynskij *et al.* 2009; Junevičius and Bogdevičius 2007, 2009; Šliupas 2009; Vansauskas and Bogdevičius, 2009; Daunoras *et al.* 2008; Dragčević *et al.* 2008; Kapski *et al.* 2008; Kinderytė-Poškienė and Sokolovskij 2008; Lundkvist and Isacsson 2008; Prentkovskis and Sokolovskij 2008; Vorobjovas and Žilionienė 2008; Bonzani 2007; Nagurnas *et al.* 2007 and 2008; Sokolovskij

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2007; Sokolovskij *et al.* 2007; Sivilevičius and Šukevičius 2007; Leden *et al.* 2006; Elvik *et al.* 1997).

For many years, Highway Patrol Police of Lithuania has been registering 3.8–6.5 thous. traffic accidents per year (Accident Rate Information 2009). The dynamics of the registered traffic accidents in 2000–2009 is shown in Fig. 1a. In 2009, 3827 traffic accidents were fixed. Their distribution in percent is presented in Fig. 1b. In Fig. 1c, percent distribution of perpetrators of traffic accidents registered in 2009 is given.

Graphical relationships presented in Fig. 1 show that:

- in recent years, traffic accident rate has been decreasing;
- collision of motor vehicles makes the largest part of all traffic accidents – 33.4%;
- drivers are usually the main traffic accident perpetrators – 73.6%.

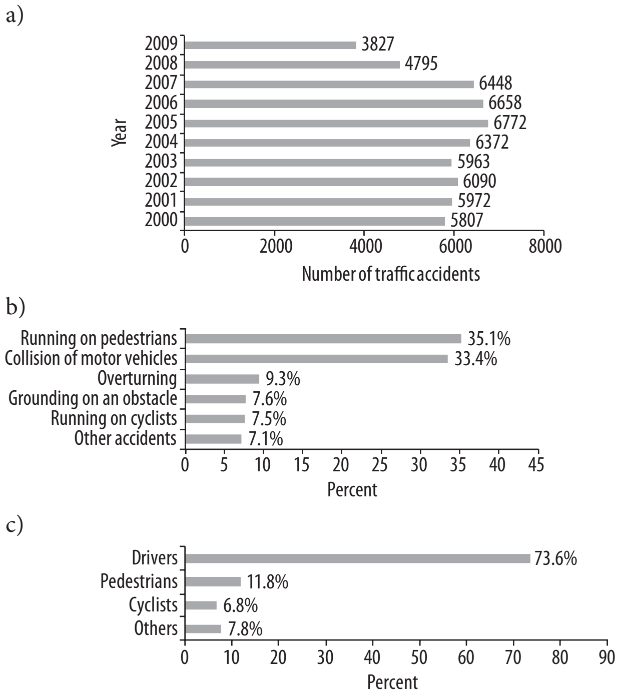

Fig. 1. Traffic accidents in Lithuania: a) is the dynamics of traffic accidents registered by Highway Patrol Police in 2000–2009; b) is percent distribution of traffic accidents registered in 2009; c) is percent distribution of traffic accident perpetrators in 2009

Now, the main causes and conditions leading to traffic accidents should be considered (Филимонов *и др*. 2007).

A detailed analysis of all types of traffic accidents can hardly be made if all causes and the related factors of traffic accidents are not determined. All types of accidents, which really occur or may occur on the road, can be described by the diagram (Fig. 2). To understand this diagram, the following definitions are made:

- *a safe traffic situation* is associated with the location and speed of motor vehicles on the road, presenting no threat to traffic participants;
- *a dangerous traffic situation* is associated with the location and speed of motor vehicles on the road, when a threat of traffic accident arises because of the wrong actions of one of traffic participants, but the accident may still be prevented;
- *an emergency situation* on the road is a dangerous situation, when an accident cannot be avoided;
- *the related factors* are circumstances influencing the development of the situation on the road, which are either easing or aggravating the consequences of a traffic accident.

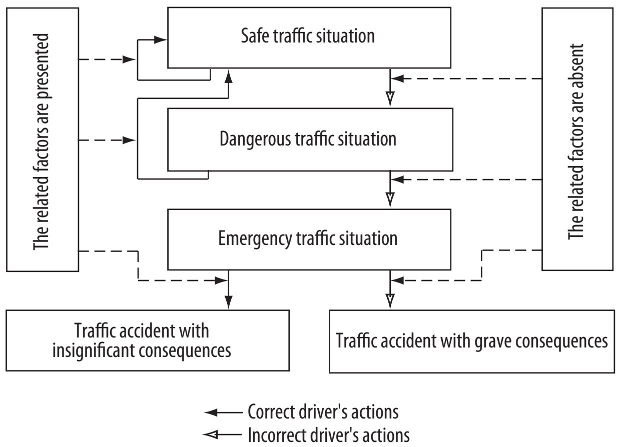

Fig. 2. A diagram demonstrating the origination and development of a traffic accident

Further, the authors of the paper will focus on the description of the most common and dangerous traffic accident – a collision of motor vehicles.

There may be head-on collisions and collisions of motor vehicles running in the same direction. The latter may also include the collisions of two or more (sometimes, very many) motor vehicles, the so-called chain collisions. Though chain collisions occur at lower speed than head-on collisions, the damage made by them is higher because a number of motor vehicles are involved. Chain collisions often occur when drivers maintain a very short distance between their and other motor vehicles ahead. In this situation, even emergency braking would not help them to avoid a collision.

Head-on collisions of motor vehicles are extremely dangerous because they cause very grave consequences, e. g. broken or completely destroyed motor vehicles, wounded or even killed people. Great energy, which the motor vehicles running towards each other at high speed possess, instantly turns into the energy destroying both human beings and goods or materials. Head-on collisions of motor vehicles are often caused by the drivers violating Traffic Rules.

2. The Related Works on the Considered Problem

A brief survey of the papers, investigating motor vehicle collisions based on the use of various models or PC-CRASH software, is presented below.

Liu *et al*. (2009) carried out the study of reproduction of car-to-car oblique crash based on reverse-reasoning calculation. According to recent traffic accident investigations and based on the developed theoretical models of tyre lateral compliance characteristics and the four-wheel simulative model, the difference in vertical load distribution on the tyre track in the working condition, as well as the impact caused by different diathesis engendered from the road surface and the complicated forces suffered by the car, were overcome to get the pre-impact motion and situation of the vehicle. Using the reverse-reasoning method for calculating the car's pre-impact motion, the whole process of the car-to-car oblique crash accident can be reproduced scientifically, and the responsibility of each party suffered in the accident can be determined. Finally, using the crash analyzing software PC-CRASH and the worked outcome in a real crash case, it has been proved that the results of reverse-reasoning calculations are reliable and may be practically applied to the analysis and evaluation of the oblique crash.

Chen and Yang (2009) made the reconstruction of a passenger car-to-child pedestrian accident. The real case of a 12-year-old child pedestrian accident in Changsha was reconstructed by using MADYMO and PC-CRASH programs to study pedestrian dynamic responses during the collision. First, PC-CRASH program was employed to find the dynamic parameters, which correlated well with the accident track according to the information from the on-spot accident investigation. These parameters were then applied to MADYMO models as boundary and initial conditions. A facet model (MBS-FACET) and a finite element model of a passenger car were developed based on the behaviour of a car during an accident. A mathematical model of the 12-year-old child was scaled down from an adult model with the SCALER module of MADYMO. The kinematic response and injury-related parameters of the child were obtained from the accident reconstructions. The results have shown that the overall kinematic response and the head impact conditions of the child in each reconstruction are quite similar. The output of head injury parameters corresponds well to the injury outcomes from clinical diagnosis.

Fan *et al*. (2008a) made a simulation based on the kinematics law of pedestrian in the vehicle/pedestrian contacting phase. Based on the coupling of PC-CRASH and embedded MADYMO, the multi-body system models of vehicle and pedestrian involved in a vehicle/pedestrian collision were developed and validated. The main factors influencing pedestrian kinematics in the vehicle/pedestrian contacting phase were extensively analyzed; furthermore, the simulation test scheme was constructed based on these factors. The kinematics laws of pedestrian such as motion posture, vehicle/pedestrian speed relationship and vehicle impact speed thresholds in the vehicle/pedestrian contacting phase under different collision circumstances were studied in depth by selecting these main influencing factors as independent variables for simulation tests. The comparisons of simulation results with real-world and staged vehicle/pedestrian collisions had shown good agreement and consistency of the kinematics law of pedestrian and vehicle interaction. The results obtained in this work could be valuable for the analysis of pedestrian kinematics in a vehicle/pedestrian collision.

Later, Fan *et al*. (2008b) evaluated the law of the influence of the pedestrian's head throw distance on the surface of the vehicle's body.

In their further research, Fan and Xu (2008) evaluated the influence of the law of the pedestrian WAD (Wrap Around Distance) in vehicle/pedestrian collisions. For computer-aided test they also used PC-CRASH and MADYMO models.

Chen *et al*. (2007) carried out the rollover far side roof strength test and simulation. Rollovers are severe road accidents. The main parts of the occupants' body injured in rollover are the head and neck that make contact with the inner part of the roof in this accident scenario. The more the roof structure intrudes during the rollover process, the higher is the chance of impact contact. Real-world roof damages in rollover accidents and PC-CRASH rollover reconstruction in vehicle dynamic analysis show that far side structure experiences more severe load in the rollover. To simulate this experimentally, roof crash test rig was designed and built on the basis of the rollover ground-roof interaction analysis. A full-size roof crash test was carried out and then numerically modelled using LS-DYNA 3D. Numerical simulation results show good agreement with the test results. The methodology of testing, simulation and evaluation of the vehicle structure provided a useful tool for improving some aspects of safe car design. The validated model provides a reliable platform for future structure optimization.

Geigl *et al*. (2003) investigated the reconstruction of occupant kinematics and kinetics for real-world accidents. A detailed study of vehicle and occupant movement during an accident is often of great interest. When reconstructing car accidents, questions regarding occupant movement and loading often arise. This paper discusses the numerical results compared to experimental test results. For two selected full-scale car to car collisions (frontal and side impact) three-dimensional vehicle movement as well as dummy accelerations were compared. A stronger emphasis was placed on the influence of the crash pulse on the occupant behaviour. In the approach used, constant acceleration during the crash phase was assumed for the occupant simulation, which was performed by coupling the three-dimensional car behaviour from PC-CRASH with a simplified MADYMO model of car interior, the restraint system and 50% tile Hybrid III dummy model.

Sokolovskij (2007) modelled the process of overturning of an automobile. The research deals with the investigation of the possibilities of the program PC-CRASH, intended for computer modelling of vehicle's movement. The computer modelling of the process of overturning of the automobile with the help of the program PC-CRASH was introduced. The cross profile of the road, the height of the centre of gravity of the automobile and other parameters were evaluated in the modelling. The influence of the introduced parameters on the computer modelling results was investigated. The possibilities of using the computer modelling programs in expert assessment of traffic accidents were considered, and the reliability of the results of modeling and the requirements raised to experts working with such programs were analyzed.

Tautkus and Bazaras (2007) were modelling and investigating car collisions. While investigating the collisions with immovable obstacles, it is necessary to determine the place of contact, its character and the speed of vehicles before the contact. These parameters depend on the obstacle. The most common cases were analyzed in the paper: a collision with an immovable obstacle which deformed only a part of the fore of the vehicle (a collision with a tree, a bollard, etc.); a collision with an immovable obstacle, which deformed the whole fore of the vehicle (a collision with a wall, etc.).

Bozhkova *et al.* (Божкова *и др*. 2009) investigated the effect of forced lateral vehicle body vibrations on its rollover, when a vehicle was bypassing an obstacle. It is well-known, that the vehicle's rollover may occur without skidding, when it bypasses an obstacle at high speed on a flat road section. In this work, a mathematical model of rollover dynamics of a vehicle bypassing an obstacle was constructed. Moreover, forced lateral vibrations of the vehicle's body, not considered in other investigations, were taken into account. As a result, it became possible to determine an optimal combination of structural and operational parameters in various types of vehicles, which could ensure their stability in bypassing obstacles.

3. Classification of the Collisions Between Motor Vehicles

Various types of motor vehicle collisions may be determined. Usually, the classification is based on the angles of pre-impact speed vectors of motor vehicles' movement with respect to each other (Иларионов 1989):

- when the angle of pre-impact motor vehicle speed vectors is 180^0 or so, a crash is referred to as *head-on collision* (see Fig. 3);
- when the angle of pre-impact motor vehicle speed vectors is 0^0 or so, it is a *collision between the motor vehicles running in the same direction* (see Fig. 4);
- when the angle of pre-impact motor vehicle speed vectors is 90^0 or so, it is a *collision between the motor vehicles running perpendicular to each other* (see Fig. 5);
- when the angle of pre-impact motor vehicle speed vectors is other than 0^0, 90^0 and 180^0 or so, it is an *oblique crash of motor vehicles (running at an angle to each other)* (see Fig. 6).

The motor vehicles may have impact or sliding collision contacts. The impact contact usually causes heavier motor vehicle deformations, when the main stronger parts of a motor vehicle are damaged. In the case of the sliding contact, the external or ornamental parts of a motor vehicle are damaged, while deformations are not so heavy as in the case of the impact contact due to the sliding of the contacting surfaces.

Thus, for example, the collision of motor vehicles running in the same or opposite direction may involve the impact contact of motor vehicles (see Figs 3a and 4a) and the sliding contact of the sides of the motor vehicles' bodies (see Figs 3b and 4b).

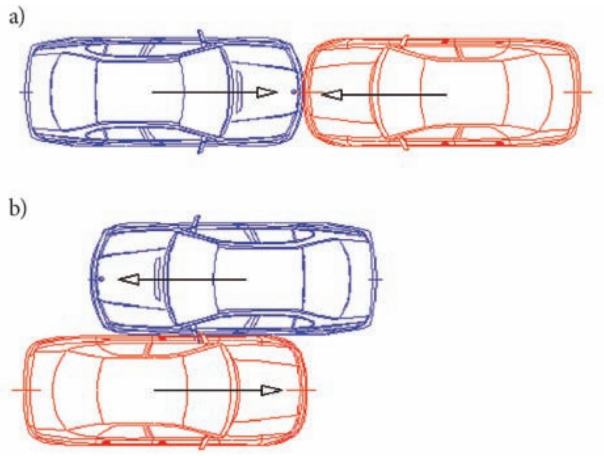

Fig 3. A head-on collision of motor vehicles

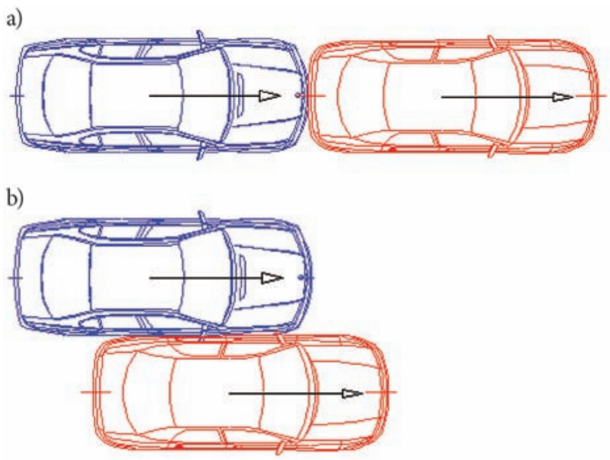

Fig. 4. A collision of motor vehicles running in the same direction

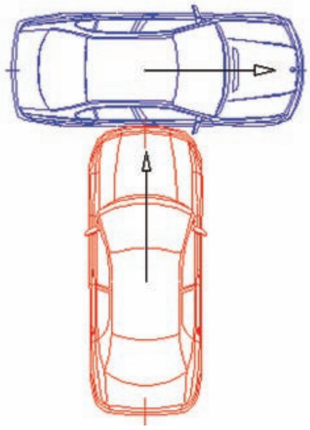

Fig. 5. A collision of motor vehicles running perpendicular to each other

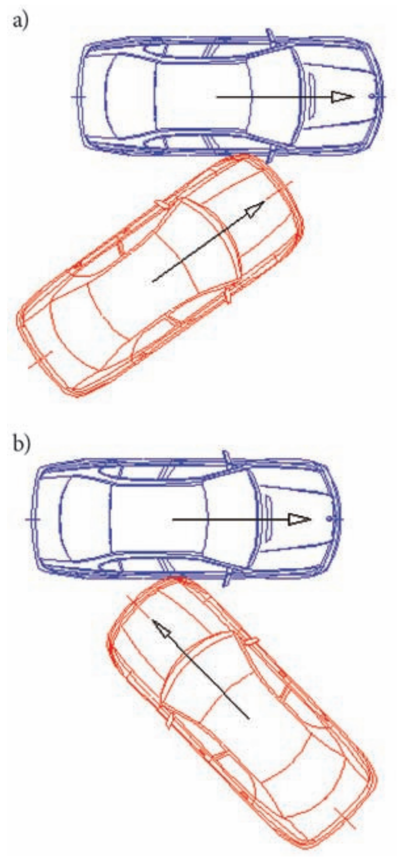

Fig. 6. A collision of motor vehicles running at an angle to each other

4. Theoretical Background Determining the Forces of Motor Vehicles' Interaction

The motion of each motor vehicle is described by the 2-nd degree Lagrange equation as the motion of a complex mechanical system:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial\{\dot{q}_{mv}\}}\right)-\frac{\partial L}{\partial\{q_{mv}\}}+\frac{\partial H}{\partial\{\dot{q}_{mv}\}}=\{F_{mv}\}, \quad (1)$$

where: L is the Lagrange function of a motor vehicle (mechanical system),

$$L = T - P, \quad (2)$$

where: T is the kinetic energy of a motor vehicle; P is the potential energy of the elastic elements of a motor vehicle; H is the dissipative function of the dissipative elements of a motor vehicle; $\{q_{mv}\}$ is the vector of the generalized coordinates of a motor vehicle; $\{\dot{q}_{mv}\}$ is the vector of the generalized speeds of a motor vehicle; $\{F_{mv}\}$ is the vector of the generalized forces acting on a motor vehicle.

A motor vehicle is a complex mechanical system, which may be modelled in terms of concentrated masses connected by elastic elements.

The potential energy of the elastic elements of a motor vehicle is equal to:

$$P=\sum_i P_i, \quad (3)$$

where: P_i is the potential energy of the i-th elastic element,

$$P_i=\frac{1}{2}\cdot k_i\cdot\Delta l_i^2, \quad (4)$$

where: k_i is the stiffness coefficient of the i-th elastic element; Δl_i is contraction of the i-th elastic element.

The dissipative function of dissipative elements of a motor vehicle is equal to:

$$H=\sum_i H_i, \quad (5)$$

where: H_i is the dissipative function of the i-th elastic element,

$$H_i=\frac{1}{2}\cdot h_i\cdot\Delta \dot{l}_i^2, \quad (6)$$

where: h_i is the damping coefficient of the mechanical energy of the i-th elastic element; $\Delta\dot{l}_i$ is the contraction rate of the i-th elastic element.

By inscribing the values of the kinetic and potential energy, the dissipative function and the vectors of motor vehicle's loading into the 2-nd degree Lagrange equation (1) we obtain the equation system of motor vehicle's motion, which may be expressed as:

$$[M_{mv}]\cdot\{\ddot{q}_{mv}\}=\{Q_{mv}\}, \quad (7)$$

where: $[M_{mv}]$ is the matrix of motor vehicle's masses; $\{\ddot{q}_{mv}\}$ is the generalized acceleration vector of a motor vehicle; $\{Q_{mv}\}$ is the vector of motor vehicle's loading,

$$\{Q_{mv}\}=\{F_{mv}\}-\left\{\sum_i\frac{\partial P_i}{\partial q_{mv}}\right\}-\left\{\sum_i\frac{\partial H_i}{\partial \dot{q}_{mv}}\right\}. \quad (8)$$

The motor vehicle's crash may be considered to be an impact in mechanical system.

The impacts in a mechanical system have the following characteristics:

- *kinematic characteristics* – the bodies of the mechanical system are interacting only for a very short time, however, the speed of particular points of the mechanical system changes considerably during the interaction;
- *dynamic characteristics* – very large impact forces develop and disappear.

Physical processes taking place during the impact are very complicated because geometric forms as well as physical and mechanical properties are various and complicated. The impact of two interacting bodies causes the development of local elastic and plastic deformations. During the interaction (impact), the speed of the bodies is changing very quickly because great forces are acting on them during the contact. These forces are rapidly growing from zero to maximum value and then are quickly decreasing to zero value again.

Two phases of motor vehicles' interaction may be distinguished:

- The *first phase* is a collision between the bodies (motor vehicles). This phase continues until two bodies (motor vehicles) approach each other. In the first phase, a part of the kinetic energy of interacting bodies is turned into their potential and thermal energy.
- The *second phase* includes further motion of the bodies (motor vehicles). The beginning of this phase is associated with the smallest distance between the contacting bodies, while its end means the loss of contact of the interacting bodies (motor vehicles). In the second phase, when the contact is achieved, the potential energy of the elastic deformation of bodies (motor vehicles) turns into their kinetic energy.

Various discrete elements are used in simulating the interaction (impact) of the bodies (motor vehicles). The models including only the elastic bonds do not allow us to determine the mechanical energy losses during the impact because the pre-impact mechanical energy of these models is their post-impact mechanical energy (e. g. a widely known Hooke's element). To be able to determine the mechanical energy dissipation, friction should be introduced into a deformable element, i.e. a model should be provided with such characteristics as viscosity or plasticity.

A collision between motor vehicles may be modelled by using viscoelastic (Kelvin–Voigt) elements.

An element of this type is applied to the interaction point of motor vehicles (on the contour of each motor vehicle in the direction of the normal).

The characteristic of the element is expressed as follows:

$$F_{k-v} = k_{k-v} \cdot x_{k-v} + h_{k-v} \cdot \dot{x}_{k-v}, \tag{9}$$

where: k_{k-v} is stiffness coefficient of the element; h_{k-v} is damping coefficient of the mechanical energy of the element; x_{k-v} is element deformation; $\dot{x}_{k-v}$ is deformation rate of the element.

The force of motor vehicles' interaction is determined (Fig. 7).

It is checked if the motor vehicles 1 and 2 are interacting. The points of intersection of the motor vehicles' contours A and B are found. In the intersection area, the average deformation (the total deformation of the bodies of two motor vehicles), which is perpendicular to the section AB, is determined. The deformation corresponding to the section S_1S_2 is also determined. The point S_1 belongs to the contour of motor vehicle 1, while the point S_2 – to the contour of motor vehicle 2.

Now, it is possible to state that:

$$x_{k-v} = S_1S_2. \tag{10}$$

Given x_{k-v}, $\dot{x}_{k-v}$ can be found:

$$\dot{x}_{k-v} = \frac{dx_{k-v}}{dt}. \tag{11}$$

The interaction force of two motor vehicles F_{k-v} is determined by formula (9).

The points of interaction force application are S_1 and S_2.

The interaction force F_{k-v} is applied to the contour of motor vehicle 1 at the point S_1. For this purpose, the direction of the normal $\{n_1\}$ at the point S_1 on the motor vehicle's contour is determined. The force F_{k-v} is projected to the normal $\{n_1\}$ and the component F_{1n} is found. The component F_{1n} is projected to the global axes X and Y.

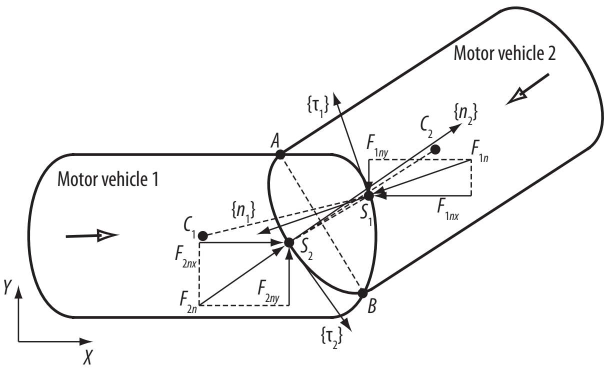

Fig. 7. A scheme of determining the interaction forces of two motor vehicles

The expressions of the tangent $\{\tau_1\}$, normal $\{n_1\}$ and binormal $\{b_1\}$ (if a collision is studied in space rather than on the plane; the binormal is not shown in Fig. 7) are as follows:

$$\{\tau_1\} = \left\{\frac{\partial r_1}{\partial t_1}\right\}; \{n\} = \frac{\left\{\frac{\partial^2 r_1}{\partial t_1^2}\right\}}{\left|\left\{\frac{\partial^2 r_1}{\partial t_1^2}\right\}\right|}; \ \{b_1\} = \{\tau_1\} \times \{n_1\}, \tag{12}$$

where: $\{r_1\}$ denotes the equation of the curves passing through a particular point of the motor vehicle's contour; t_1 is the parameter of the curve.

The interaction forces acting on motor vehicle 1 make up the vector $\{F_1\}$.

Then, the moment $\{M_1\}$ of the interaction force $\{F_1\}$ acting on motor vehicle 1 is determined

$$\{M_1\} = \{r_{CS_1}\} \cdot \{F_1\}, \tag{13}$$

where: $\{r_{CS_1}\}$ is a local vector directed from the centre of motor vehicle masses to the point of force application.

Both vectors $\{F_1\}$ and $\{M_1\}$ are introduced into the vector $\{F_{mv}\}$, see expression (8).

The components of the interaction force acting on motor vehicle 2 are found in a similar way.

The interaction force of two motor vehicles is a major factor influencing the pre- and post-impact performance of these motor vehicles (e. g. movement trajectories, speed, etc.) therefore, the authors provide a description of an algorithm used for determining the interaction force of two motor vehicles.

As mentioned above, a collision of several motor vehicles, as well as their interaction with the environment, present big problems, when safe traffic should be ensured. They have been analysed not only in the works of the authors of the present paper but by many Lithuanian and foreign researchers (for example, Prentkovskis *et al.* 2007, 2008, 2009, 2010; Vansauskas and Bogdevičius 2009; Viba *et al.* 2009; Dragčević 2008; Prentkovskis and Sokolovskij 2008; Pelenytė-Vyšniauskienė and Jurkauskas 2007; Sokolovskij and Pečeliūnas 2007; Wu and Thomson 2007; Cansiz and Atahan 2006; Ibitoye *et al.* 2006).

5. Simulating the Collisions Between Motor Vehicles

Examining traffic accidents, computer-aided simulation is commonly used to reconstruct the circumstances of an accident and to determine pre-impact speed of motor vehicles. For this purpose, special computer programs are applied (e. g. PC-CRASH, MADYMO, LS-DYNA, CARAT, PAM-CRASH, RADIOSS, etc).

The present investigation is based on the use of the program PC-CRASH (PC-CRASH: A Simulation … 2007).

In different traffic accidents, the post-impact speed and movement of the motor vehicles varies to some extent. Various simulated traffic accidents (the collisions of motor vehicles) and their speed–distance diagrams are demonstrated below. The simulation was based on the use of the computer program PC-CRASH 8.1. Motor vehicles (BMW 320i – motor vehicle 1 and Mercedes Benz C220 – motor vehicle 2) and their parameters were taken from the program's database. In all cases of simulated traffic accidents, the deceleration of motor vehicles after collision was assumed to be 6 m/s^2. Simulation results and speed–distance diagrams are given in Figs 8–11. The collided motor vehicles are shown at the moment, when their contours are coming into contact (without intrusion), but not at the time when the heaviest deformations of their bodies are being developed. This was made in order to simulate and assess in diagrams all phases of collision, including the movement of motor vehicles at the initial speed, the moment of their first contact, the impact, departure of motor vehicles and their post-impact movement until coming to a stop. Moreover, the loss of motor vehicles' energy during the impact due to the development of deformations of their bodies was evaluated.

The points of sharp speed changes in the diagrams match the impact.

In simulating the collisions of motor vehicles running in the opposite and the same direction (see Figs 8 and 9), the speed of motor vehicle 1 was assumed to be 60 km/h, while the speed of motor vehicle 2 was assumed to be 10 km/h. It can be observed that the main difference between the head-on collisions of motor vehicles and the collisions of motor vehicles running in the same direction lies in the fact that, in the latter case, the motor vehicles are displaced over longer distances than in the first case because the directions of their speed vectors match. In addition, as shown by the speed–distance diagrams, the speed of motor vehicle 1 is decreased more and the speed of motor vehicle 2 is increased less in a head-on collision. This is because pre-impact speed vectors of motor vehicles are directed in opposite direction in this situation. In this case, heavier deformations of motor vehicles' bodies can also be observed.

In modelling the collisions of motor vehicles running perpendicular to each other and oblique crashes (see Figs 10 and 11), the speed of both motor vehicles was assumed to be equal to 50 km/h. It can be seen, that in the cases of the collision of motor vehicles running perpendicular or at an angle to each other (Figs 10 and 11), they continue their movement after collision at a certain angle to the initial direction. The speed–distance diagram of motor vehicles running perpendicular to each other (see Fig. 10) shows that after a sudden change of the motor vehicle's speed, some further insignificant speed changes may be observed. This means that the second contact follows the first one (a collision of motor vehicles).

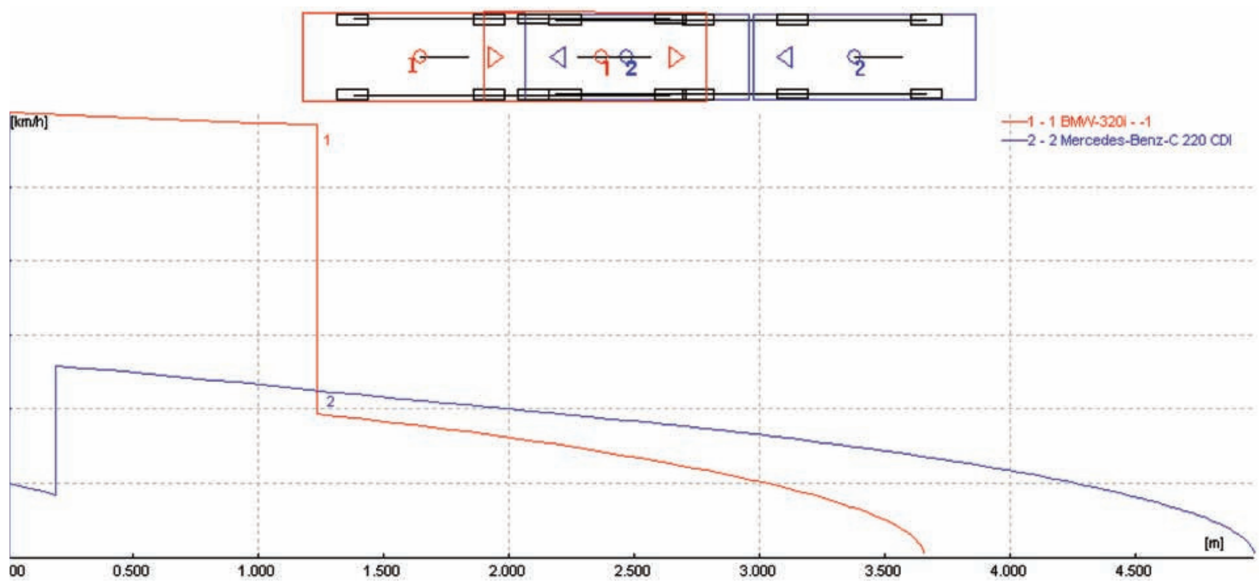

Fig. 8. Simulation of a head-on collision of motor vehicles and their speed–distance diagram

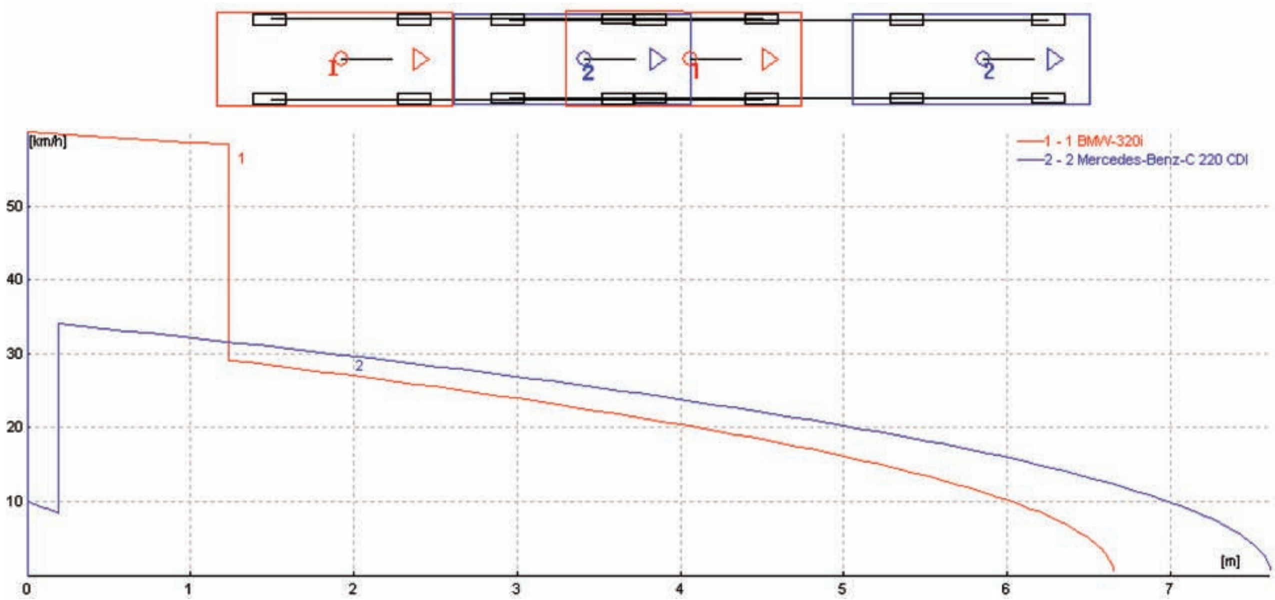

Fig. 9. Simulation of a collision of motor vehicles running in the same direction and their speed–distance diagram

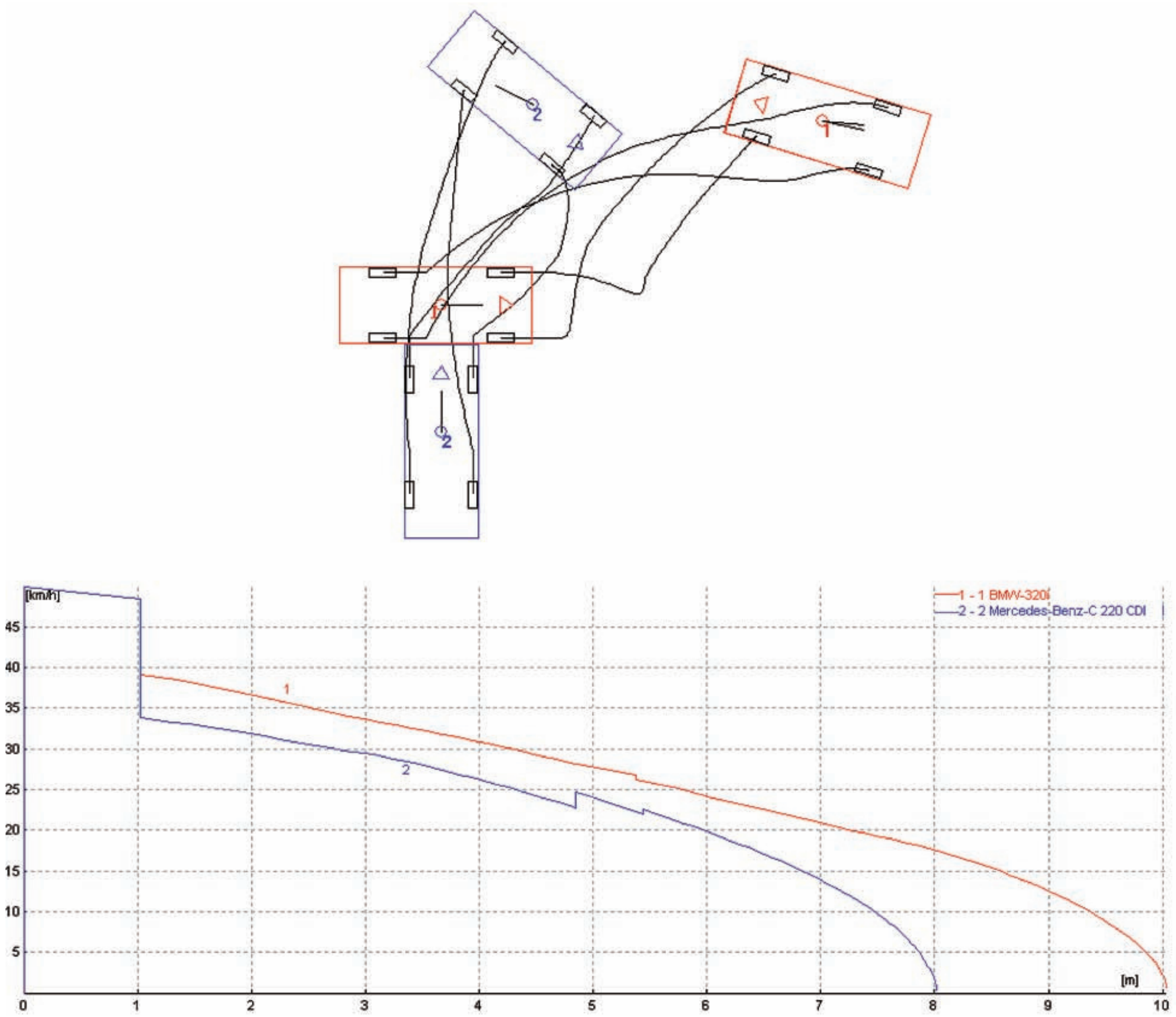

Fig. 10. Simulation of a collision of motor vehicles running perpendicular to each other and their speed–distance diagram

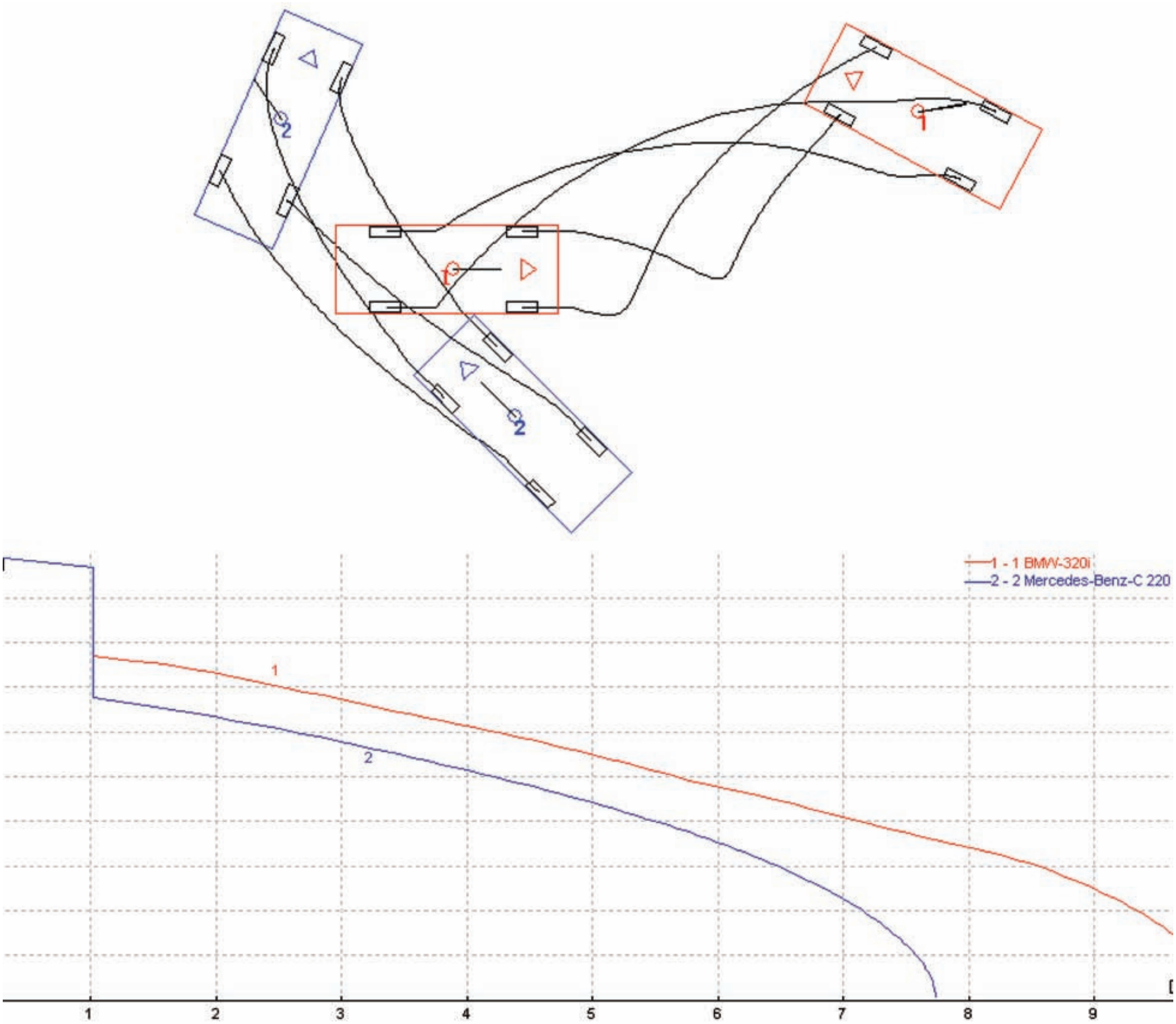

Fig. 11. Simulation of the oblique crash of motor vehicles and their speed–distance diagram

6. Conclusions

1. The analysis of statistical data on the rate of traffic accidents in 2000–2009 (Fig. 1) shows that, in recent two years, the number of traffic accidents registered by Highway Patrol Police of Lithuania has decreased by about 1.3–1.6 times. Collisions of motor vehicles make one of the largest part of all traffic accidents – 33.4%. Drivers are usually the main traffic accident perpetrators – 73.6%.
2. The computer-aided experiment, the simulation of interaction between two motor vehicles, was based on the use of the software package PC-CRASH 8.1, aimed at investigating various traffic situations. Speed-distance diagrams were developed.
3. The conducted computer-aided experiment, the simulation of interaction between two motor vehicles, allowed the authors to conclude that the main difference between the head-on collisions and the collisions of motor vehicles running in the same direction is that, in the latter case, the collided motor vehicles slip over a larger distance because of the matching speed vectors (Figs 8 and 9). Moreover, as shown by the speed–distance diagrams, in the case of a head-on collision, the speed of the first motor vehicle is decreasing more and the speed of the second motor vehicle is increasing less than in the collision of motor vehicles running in the same direction. This may be accounted for by the fact that a part of energy is used to decelerate the second motor vehicle because, in this case, the direction of speed vectors of the motor vehicles before the collision is different. Usually, heavier deformations of motor vehicle body can be also observed. It can be seen, that in the cases of the collision of motor vehicles running perpendicular or at an angle to each other (Figs 10 and 11), they continue their movement after collision at a certain angle to the initial direction. The speed–distance diagram of motor vehicles running perpendicular to each other (see Fig. 10) shows that after a sudden change of the motor vehicle's speed, some further insignificant speed changes may be observed. This means that the second contact follows the first one (a collision of motor vehicles).

4. The paper considers some major aspects of motor vehicle collision simulation based on the application of PC-CRASH 8.1 software allowing researchers to analyze the changes of motor vehicle motion direction in the case of collision and the influencing factors. This type of traffic accident simulation consists in studying the circumstances of collision, reconstructing the processes, calculating the pre-impact speed of motor vehicles and determining various parameters of motor vehicles' movement at different stages of traffic accident development.

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