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# COMPUTER-RUN SIMULATION OF ROLLOVER OF THE MOTOR VEHICLE

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The theoretical model of motor vehicle movement and rollover is presented. This model consists of three models: model of the motor vehicle; model of the road pavement surface; model of the interaction between the motor vehicle's wheel and the road pavement surface. The computer-run simulation of rollover of the motor vehicle with the help of the PC CRASH software is introduced.

***Keywords:*** *motor vehicle, rollover, computer-run simulation, traffic accident*

## 1. Introduction

One of the main tasks of transport is the increase of the amount of transported goods as well as retaining traffic safety.

All accidents, occurring in Lithuania, can be classified into the following types: collision; rollover; hitting an obstacle; hitting the parked vehicle; running on pedestrians; running on cyclists; other accidents. According to the statistical data, rollovers make up about 12 % of all accidents in our country [1-3]. There occur some 6500 road accidents per year in Lithuania [4].

Traffic safety is becoming not only a moral, social, economical, but also a political problem in Lithuania. This problem has to be solved as quickly as possible, because Lithuania is considered to be a country of greater risk, which is very important, when integrating road transport into the European transport system.

Rollover is a type of motor vehicle accident, where a motor vehicle turns over on its side or roof. The main cause for rolling over is turning too sharp while moving too fast.

The force of inertia (acting in the direction opposite to the one it is turning) is combined with the force of gravity (acting downwards). When the combined force as applied to the centre of motor vehicle's mass falls outside of the rectangle formed by the wheels, the motor vehicle starts to turn over (Fig. 1). A rollover can also occur as a motor vehicle crosses a ditch or barrier rather than a flat road surface. Such an event can be triggered by a sudden turn to avoid a collision, or a loss of traction due to water or ice.

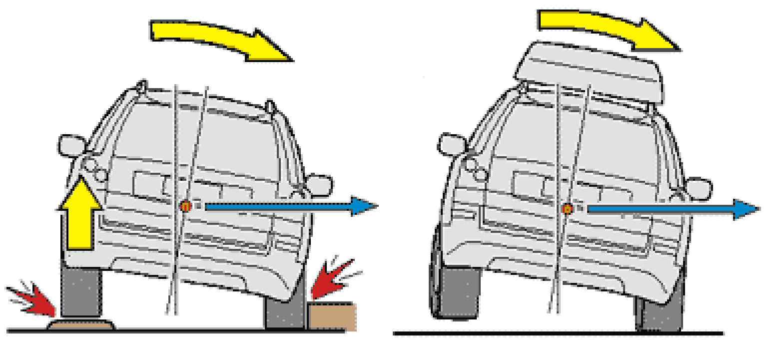


***Figure 1**. Scheme of rollover of the motor vehicle*

Simulation of the rollover of the motor vehicle can be divided into three stages:
1. simulation of the motor vehicle and its movement;
2. simulation of the road pavement surface;
3. simulation of the interaction between the motor vehicle's wheel and the road pavement surface.

At present many software for simulation of the movement of motor vehicles, which are usually meant for investigation of the traffic accidents, have been created in the world. These software become more and more improved, seeking to evaluate as many factors as possible so that the results of the computer-run simulation are brought closer to the results of the real experiments.

## 2. Theoretical Part

Movement of the motor vehicle and its rollover are simulated on a certain road section in the system of global coordinates $X-Y-Z$, which does not move in space. The road does not change its position (does not move) with respect to this system of coordinates. The motor vehicle moves with respect to the system of coordinates mentioned above. Together with the motor vehicle, local systems of coordinates of the motor vehicle move with respect to the system of coordinates $X-Y-Z$.

The investigated road section has certain known physical and mechanical properties (for example, vertical roughness of road pavement surface, traction coefficients of the wheel and the road pavement surface etc.).

A typical motor vehicle with known masses and geometrical parameters is selected for investigating its movement and rollover.

***Road pavement surface model.*** Vertical roughness of road pavement surface (for example, pits, shoulders etc.) influence the movement of the vehicle during its rollover. The road pavement surface can have different heights of profiles in different places. Various traction coefficients of road pavement and motor vehicle wheel can be calculated in different spots of the road pavement surface under different climatic conditions (for example, water, snow, ice, ground, dry or wet asphalt etc. can be on the road pavement surface), which influence the movement of the motor vehicle.

To describe road pavement surface roughness and traction coefficients of road pavement and motor vehicle wheels on every spot of the road pavement surface, the Finite elements method is applied [1-3].

The total pavement surface of the road section is divided into finite elements, for example triangular finite elements (Fig. 2). A certain height of the road pavement surface and traction coefficients of road pavement and motor vehicle wheels in the longitudinal and transverse directions are selected in every node of finite element [2, 3].

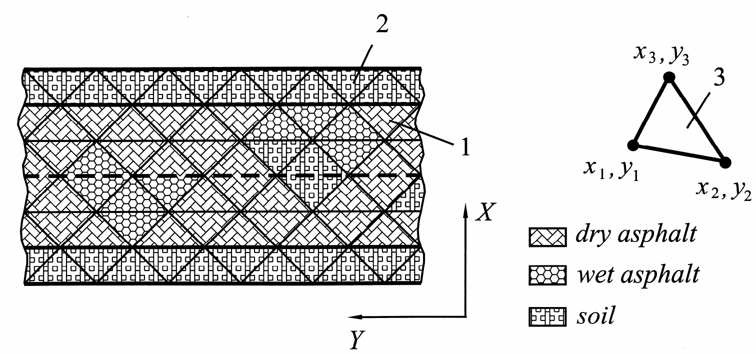



***Figure 2.*** *Road pavement surface model: 1 – road carriageway; 2 – shoulder; 3 – triangular finite element*

The roughness of the surface in every point ( $x$, $y$ ) of finite element are approximated as follows:

$$\xi(x, y) = [N(x, y)]\{\xi\}; \qquad (1)$$

where: $\xi(x, y)$ – road pavement surface roughness in finite element point $x$, $y$; $[N(x, y)]$ – shape functions of triangular finite element; $\{\xi\}$ – surface roughness in finite element nodes.

Traction coefficients of the wheel and the road pavement surface in any finite element point ( $x$ , $y$ ) are approximated as follows:

$$\varphi_{trac}^{\max}(x, y) = [N(x, y)]\{\varphi_{trac}^{\max}\}; \quad \varphi_{trac}^{\min}(x, y) = [N(x, y)]\{\varphi_{trac}^{\min}\}; \tag{2}$$

where: $\varphi_{trac}^{\max}(x, y)$, $\varphi_{trac}^{\min}(x, y)$ – maximum and minimum traction coefficients of the wheel and the road pavement surface on finite element point ( $x$ , $y$ ); $[N(x, y)]$ – shape functions of triangle finite element; $\{\varphi_{trac}^{\max}\}$, $\{\varphi_{trac}^{\min}\}$ – vectors of maximum and minimum traction coefficients on finite element nodes.

Road pavement surface roughness and traction coefficients of the wheel and the road pavement surface are divided linearly in the finite elements, therefore, the net of finite elements shall be denser in the places, where surface roughness or traction coefficients change rapidly (increase or decrease).

To perform fewer calculations, it shall be estimated to which of the finite element every wheel belongs and heights of road pavement surface roughness and traction coefficients of the every wheel and the road pavement surface are estimated only in four selected points (under four motor vehicle wheels).

***Motor vehicle model.*** The motor vehicle is simulated by concentrated masses interconnected by elastic and dissipative links (Kelvin-Foight elements). The motor vehicle model consists of seven concentrated masses: body, front and rear suspension and four wheels (Fig. 3).

To describe the movement of the motor vehicle, the following generalized coordinates are introduced:

$$\{q_{mv}\}^T = [x_C \quad y_C \quad z_C \quad \varphi_{x_C} \quad \varphi_{y_C} \quad \varphi_{z_C} \quad z_1 \quad \varphi_1 \quad z_2 \quad \varphi_2 \quad z_{w1} \quad z_{w2} \quad z_{w3} \quad z_{w4}]. \tag{3}$$

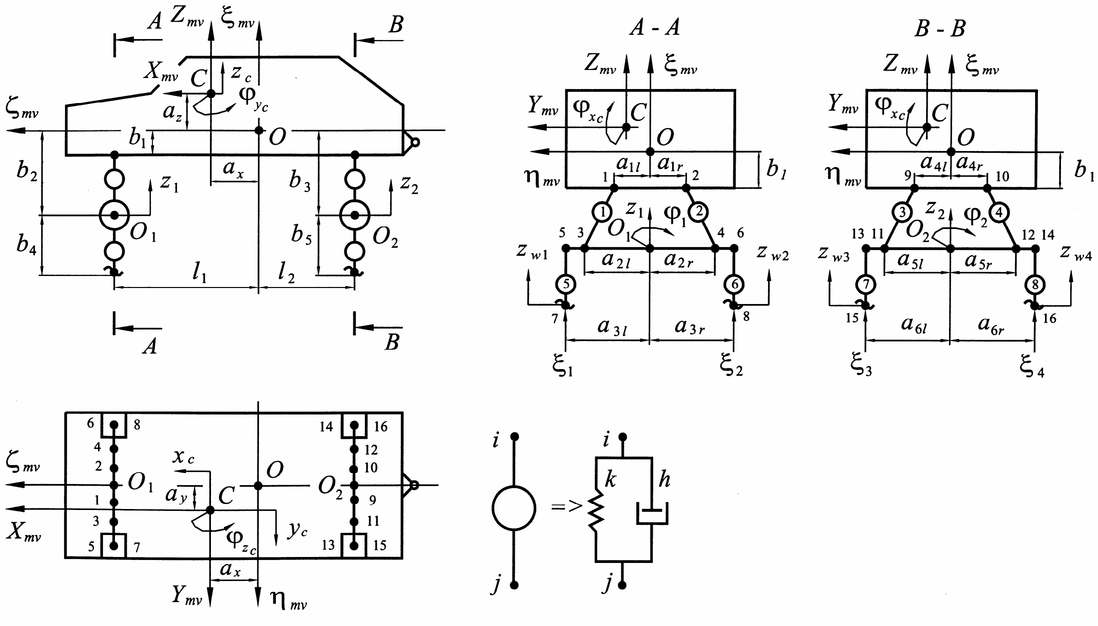



***Figure 3.*** *Motor vehicle model*

Movement of the motor vehicle, as movement of an intricate mechanical system, is described by second degree Lagrange equations [1-3], which can be written in the matrix form:

$$[M_{mv}]\{\ddot{q}_{mv}\} = \{Q_{mv}\}; \tag{4}$$

where: $[M_{mv}]$ – motor vehicle masses matrix; $\{\ddot{q}_{mv}\}$ – motor vehicle generalized accelerations vector; $\{Q_{mv}\}$ – motor vehicle loading vector.

The system of equations (4) is solved by the method of Runge-Kutta [2, 3, 5]. For this purpose, it has to be rearranged from 14 differential equations of the second order to 28 differential equations of the first order:

$$\begin{cases} \frac{d}{dt}\{q_{mv}\} = \{\dot{q}_{mv}\}; \\ \frac{d}{dt}\{\dot{q}_{mv}\} = [M_{mv}]^{-1}\{Q_{mv}\}. \end{cases} \quad (5)$$

***Model of interaction between the motor vehicle's wheel and the road pavement surface.*** When solving system of equations (5), contact between the wheel and road pavement surface has to be evaluated in every time step.

The following conditions of contact between the motor vehicle wheel and road pavement surface are selected (Fig. 4):

$$z_{wj} = \begin{cases} z_{wj}, & when \quad z_{wj} \geq \xi_j; \\ \xi_j, & when \quad z_{wj} < \xi_j; \end{cases} \qquad \dot{z}_{wj} = \begin{cases} \dot{z}_{wj}, & when \quad z_{wj} \geq \xi_j \quad and \quad \dot{z}_{wj} \geq 0; \\ 0, & when \quad z_{wj} < \xi_j \quad and \quad \dot{z}_{wj} < 0; \end{cases}$$

$$\ddot{z}_{wj} = \begin{cases} F_{eq\ j+10}, & when \quad z_{wj} \geq \xi_j \quad and \quad F_{eq\ j+10} \geq 0; \\ 0, & when \quad z_{wj} < \xi_j \quad and \quad F_{eq\ j+10} < 0; \end{cases} \quad (6)$$

where: $\xi_j$ – heights of road pavement surface roughness under motor vehicle wheels, $j = 1 \div 4$; $F_{eq\ j+10}$ – motor vehicle movement equations right side obtained with respect to $\dot{z}_{wj}$.

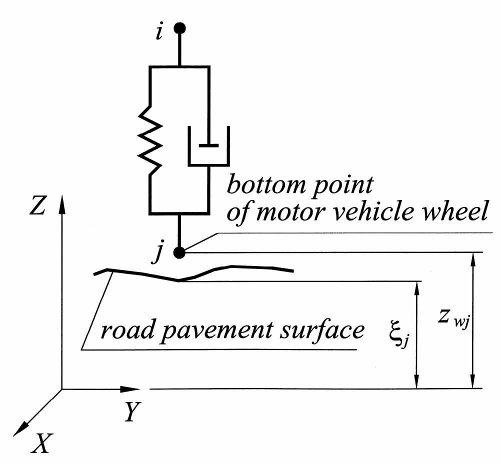



***Figure 4.*** *Identification scheme of the contact between motor vehicle wheel and road pavement surface*

## 3. Results of Computer-Run Simulation

The PC CRASH is one of the software's, meant for simulation of the motor vehicles movements [6-9]. PC CRASH™ is a WINDOWS™ collision and trajectory simulation tool that enables the accurate analysis of a wide variety of motor vehicle collisions and other incidents. Results are viewed as 3D-animations and detailed reports, tables and graphs.

While simulating with the help of the PC CRASH software, firstly the definite model of the motor vehicle, the movement of which is to be simulated, together with its appropriate characteristics is selected from the database.

Various regimes of the movement (braking, acceleration) of the motor vehicles, parameters of the deceleration and acceleration of the movement can be set.

There is a possibility to select and, while simulating, to evaluate such parameters of the motor vehicle as the parameters of suspension, the degree of loading of the motor vehicle, the type of the tires, distribution of the braking forces etc.

The traction coefficient is set for the whole surface, afterwards the other traction coefficient can be introduced for separate sections of road.

After having selected the traction coefficient, the software automatically selects the maximal possible deceleration of the motor vehicle. It’s possible, on the contrary, to introduce the value of deceleration, afterwards the traction coefficient is to be recalculated. Besides, there is a possibility to introduce deceleration, as the function, from the speed. In this case, deceleration is simulated as the hyperbolic function, the parameters of which are calculated by introducing the values of deceleration, with taking into consideration the speed of movement of the motor vehicle, equal to 20 and 80 km/h. This model mostly suits for braking on a wet section of the road, when the speed is larger. However, it does not suit for simulating the movement of the motor vehicle after the crash, when dependence of the deceleration upon the speed may be of a completely different nature.

However, while simulating with the help of the PC CRASH software, it’s possible not only to ascertain the speed of the motor vehicle prior to its rollover, but to restore the movement of the motor vehicle while rollover as well.

The possibility to simulate the movement of the motor vehicle in the space (i.e. of the movement in the three planes) with taking into consideration such parameters as the profile of the road, including the cross profile, location of the centre of gravity of the motor vehicle is one of the advantages of the PC CRASH software. It’s very important because, without this possibility (for example, while simulating in the plane), it would be impossible to restore such a complex movement of the motor vehicle as the rollover of the motor vehicle.

There rollover of AUDI-100 is investigated.

Figs. 5-7 reflect the simulated rollover of the motor vehicle, when the latter moves down from the slope of the road. Besides, the PC CRASH software provides the possibility to observe the view in the space (Figs. 6-7). In this case, while simulating the movement of the motor vehicle according to the available data, the cross profile of the definite road section was introduced (Fig. 7). Without having evaluated the latter, the motor vehicle would be moving further on, without rollover.

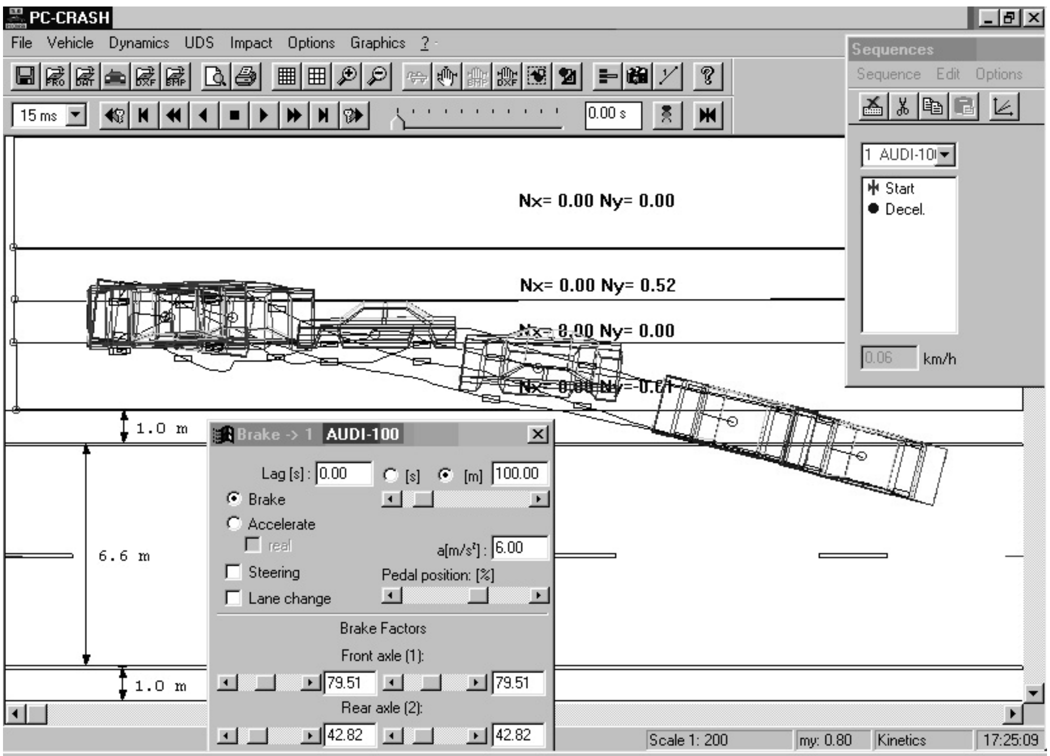
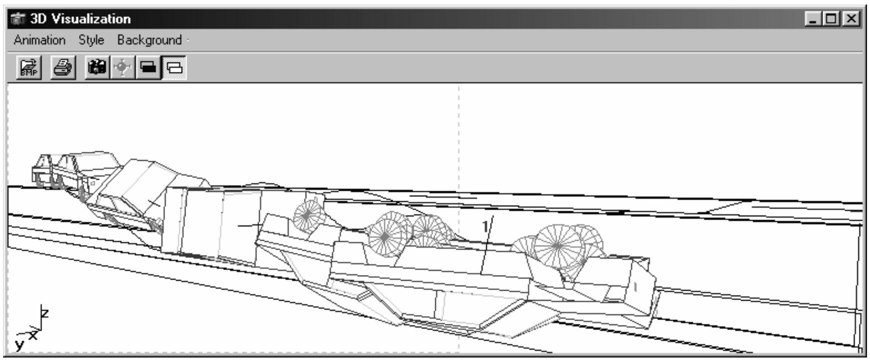
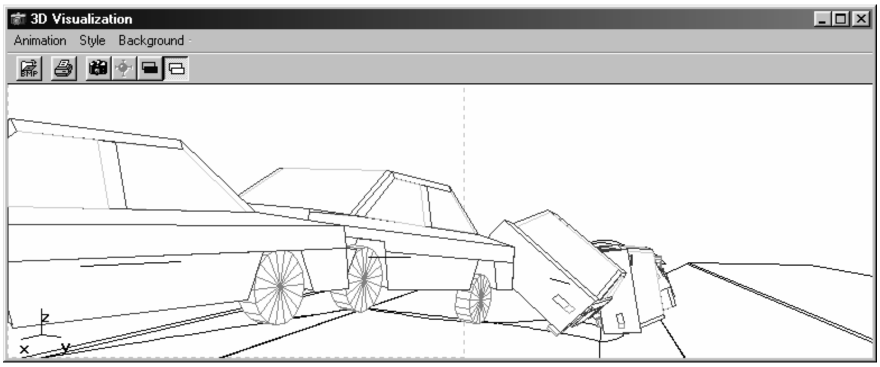



***Figure 5.*** *The view of rollover of the motor vehicle from above*




a)




b)

***Figure 6.*** *The view of rollover of the motor vehicle in the space: a – from the front; b – from the back*

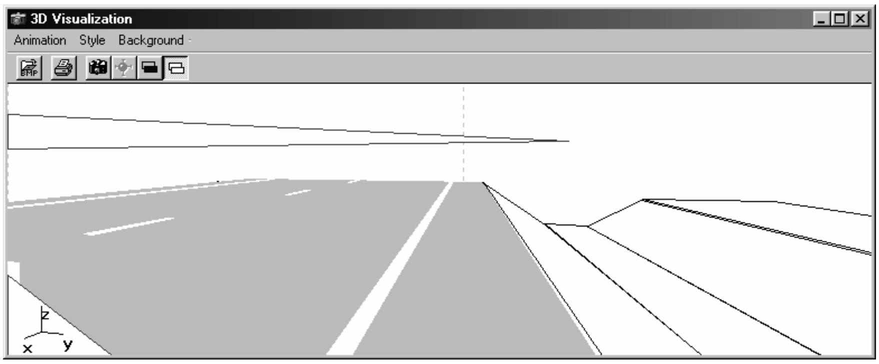



***Figure** 7. The cross profile of the road*

The computer-run simulation of rollover of the motor vehicle, which was carried out, proves that the results of simulation depend upon the introduced parameters very much. In this case, having not evaluated the cross profile of the road, the height of the centre of gravity of the motor vehicle and the other parameters, a completely different result may be obtained.

Thus, seeking for reliability of the results of simulation of the course of the traffic accidents, it's very important that the experienced expert, having the appropriate qualification in introducing the necessary parameters and having enough skills of work with the computer-run simulation software, carries out the computer-run simulation. Only in this case the results of simulation will be reliable and can be used in the expert assessment of the traffic accidents.

## 4. Conclusions

1. The theoretical model of motor vehicle movement and rollover is presented. The model consists of three models: model of the motor vehicle; model of the road pavement surface; model of the interaction between the motor vehicle's wheel and the road pavement surface.

2. Computer-run simulation software PC CRASH makes the work, carried out by the experts of investigation of the traffic accidents, easier, especially wishing to model several possible variants. The software permits to evaluate various parameters, such as the parameters of the surface of the road (the traction parameters), the parameters of the motor vehicle (the parameters of suspension, the degree of loading of the motor vehicle, the type of the tires, distribution of the forces of braking, etc.) and provide the possibility to model various regimes of the movement of the motor vehicle and such complex processes as rollover of the motor vehicle.
3. The computer-run simulation of rollover of the motor vehicle, which was carried out, proves that the results of simulation depend upon the introduced parameters very much. In this case, having not evaluated the cross profile of the road, the height of the centre of gravity of the motor vehicle and the other parameters, a completely different result may be obtained.

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