**VUK BOGDANOVIĆ**, Ph.D.
E-mail: vuk@uns.ac.rs
University of Novi Sad, Faculty of Technical Sciences
Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia
**NENAD MILUTINOVIĆ**, M.Sc.
E-mail: nenadmilu@yahoo.com
Technical College of Applied Studies
Kosovska 8, 34000 Kragujevac, Serbia
**SVETOZAR KOSTIĆ**, Ph.D.
E-mail: sasakostic49@gmail.com
**NENAD RUŠKIĆ**, M.Sc.
E-mail: nruskic@uns.ac.rs
University of Novi Sad, Faculty of Technical Sciences
Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia

# RESEARCH OF THE INFLUENCES OF INPUT PARAMETERS ON THE RESULT OF VEHICLES COLLISION SIMULATION

## ABSTRACT

*Vehicle collisions are complex processes which are determined by a large number of different parameters. The development of computer programs for simulation has made the collision analysis and reconstruction procedure easier, as well as the possibility to realise the influences of different parameters on collision processes, which was not possible while using classical methods. The quality of results of vehicle collision simulation and reconstruction is expressed by an error which is determined on the basis of the difference between vehicles stopping positions, which was obtained by the simulation of established vehicles stopping positions in real collisions. Being acquainted with the influence of collision parameters on the simulation error enables the development of more reliable models for automatic optimisation of the collision process and reduction of the number of iterations in the procedure of a collision reconstruction. Within the scope of this paper, the analysis and classification of different collision parameters have been carried out. It has been done by the degree of the influence on the error in the simulation process in the software package Virtual CRASH. Varying twenty different collision parameters on the sample of seven crash tests, their influence on the distance, trajectory and angular error has been analysed, and ten parameters with the highest level of influence (centre of gravity position from front axle of vehicle 1, restitution coefficient, collision place in longitudinal direction, collision place in transverse direction, centre of gravity height-vehicle2, centre of gravity height-vehicle1, collision angle, contact plane angle, slowing down the vehicle and vehicle movement direction) have been distinguished.*

## KEY WORDS

*collision, vehicles, parameters, simulation, error*

## 1. INTRODUCTION

Computer programs have been used since the early 1970s for analysing traffic accidents [1]. They enable fast and efficient establishing of the point of impact, velocity and the position of the accident participants at the moment of the collision, as well as the analysis of the possibility for avoiding accident in different conditions. Besides, these programs have the possibility of visualisation and 3D demonstration of the collision process kinetics and dynamics in different stages. Due to a range of advantages in relation to classical procedures for traffic accidents analyses, today they play an important part in the reconstruction and analysis of different types of traffic accidents. The same as with other program tools, the results of vehicle collision analyses primarily depend on the input data. Inexpert using of these programs or their misuse can lead up to wrong results and conclusions about the analysed traffic accident [1].

Programs based on impulse method are mostly used in Europe, and in the world other programs are used as well, such as SMAC (Simulation Model of Automobile Collisions) [2, 3, 4] and CRASH (Computer Reconstruction of Accident Speeds on the Highway) [2, 5].

Programs for collision simulation enable manual or automatic collision process repeating, and after a series of attempts, it is possible to choose the simulation which is the most authentic in demonstrating the real traffic accident, respecting all the previously determined facts and material traces [2].

Simulation of vehicle collision processes means one or more input parameters varying in order to ap-

proach vehicles stopping positions obtained by simulation as similar as possible to the real stopping positions of the vehicles which participated in the real collision.

Very often, vehicles stopping positions obtained in the simulation differ from the stopping positions of the vehicles in the real collision, which is expressed as the simulation error. The error value depends on the accuracy of the input parameters given by the operator, that is, to what extent their value differs from the real, factual conditions. If the error is big, other results or input parameters of the collision process simulation, like the point of collision, vehicle positions at the moment of the collision, the velocity at the moment of the collision, etc., cannot be taken into consideration as relevant. In order to reduce the error as much as possible, the collision input parameters are varied manually or automatically.

Moser has defined the model for automatic optimisation of collisions on the basis of post-collision trajectory and the stopping position of vehicles [6]. Previous practice has shown that sometimes, after reducing the error of stopping positions by automatic optimisation, other parameters of the collision process and material evidence do not match up. These results pose the question which parameters of the collision and to which extent they should be varied so that the stopping positions match the material evidence.

Spit [7, 8] during the program PC-CRASH validation, carried out the analysis of the program sensitivity referring to the study of small changes in the input values, but on that occasion he took into account a few inputs (the position of vehicle's centre of gravity, the vehicle's mass, restitution coefficient) and he did not study the influence degree of these parameters on computer analysis of the crashes.

In order to optimise the process of collision simulation and approach as much as possible the process of the real collision by modelling it, it is necessary to study and define the influence of different input parameters of the collision process.

## 2. INPUT PARAMETERS IN COLLISION PROCESSES SIMULATIONS

Simulation is a process of real system modelling – modelling of a group of objects which are in interaction and enable the study of the influence of some system elements on the behaviour of the system itself. A traffic accident simulation makes it possible to study the influence of input parameters relevant to the accident flow and represents a very efficient tool for explaining the circumstances related to its occurrence [9].

For a collision process simulation it is necessary to define different input parameters which are used for

defining the collision kinematics, that is, the vehicle velocity, the way and direction of the vehicle motion and the point of collision, and these are: the vehicle motion direction immediately before the collision, the point of collision in longitudinal and transversal direction, the angle of the collision and the contact plane, the width of the vehicle overlap in the collision, the vehicle slowing down before the collision and the collision velocities.

Defining kinematics parameters of the collision is usually done on the basis of the analysis of the traces found on the spot, as well as on the basis of the damage on the collision vehicles [10]. Different forensic actions can be significant in defining these parameters, in terms of defining the source and dynamics of traces formation. Determining the point of collision and other parameters used for defining the vehicle motion immediately before the collision can be a complex process, despite having different traces, and especially in the situation when there are no material traces.

Alongside the parameters for defining the kinematics of vehicle motion, the position of the vehicles at the moment of the collision and the point of collision, for the simulation of the collision process it is necessary to define the parameters used for defining the dynamics of the collision, and these are: restitution coefficient, vehicle mass and their distribution, the height of the vehicle's centre of gravity, the position of the centre of gravity in relation to the front axle of the vehicle, the coefficient of the friction between the vehicles, the penetration time - compression, the impulse point in the direction of X, Y and Z axes and the vehicle slowing down during the movement towards the stopping position.

In reconstructing the real traffic accident by simulation, it is not possible to determine some input parameters exactly, therefore they are expertly evaluated. First of all, it refers to the restitution coefficient which can be calculated in two ways, as described by Baptista [11], and the vehicle-vehicle friction coefficient. However, all system parameters and conditions at the beginning differ in terms of influence on the simulation results, thereby on the time necessary for finding a satisfactory solution with acceptable values of the total error [8].

## 3. BASIC CHARACTERISTICS OF THE PROGRAM FOR COLLISION SIMULATION

Programs for collision simulation are based on the laws of motion amount sustainability or the laws of energy conservation [12]. Most of the programs intended for computer simulation of vehicle collisions on the territory of the USA are based on CRASH and SMAC methods, unlike subsequently developed programs in Europe which are solely based on the impulse colli-

sion model. Most of the present program packages for analysing vehicle collisions have been created as a compilation of models, subprograms and functions of the earliest programs of this type (CRASH, SMAC), developed in Aeronautics laboratory Calspan. Basically, they all use similar basic algorithms regarding vehicle motion modelling before and after the collision, with the difference that impulse type programs have other ways for modelling the very collision process.

In the 1990s many programs for collision simulation were developed from the program SMAC, such as: EDSMAC, WinSMAC and m-SMAC, After advancing certain modules, functions and results presentations from the program CRASH, some new programs were developed: EDCRASH, PC-CRASH, CRASHEX, SLAM, WINCRASH [5], and afterwards programs CARAT, Analyzer Pro and Virtual CRASH.

The analysis principles with all the stated programs for collision simulation and reconstruction are similar. Varying any of the input information demands repeating the complete simulation process, therefore, it is sometimes necessary to repeat the simulation a few hundred times to find the solution which corresponds to the real collision. For this reason, some programs have developed automatic optimisers which automatically vary input data in the given frameworks. However, even these programs have some constraints, considering that optimisation process can be carried out varying any collision parameter individually or in combination with other parameters. Altering certain collision parameters insignificantly influences the collision simulation result. Therefore, by simple certain parameters variation, it is not possible to accord the simulation with material traces and facts from the real collision being analysed. If the influence degree of some parameters on the collision process was defined and profiled, then the process of collision optimisation would

be faster and more efficient. With the programs which do not have the possibility of automatic optimisation or automatic iteration of the simulation, the question is which parameters have the biggest influence on the simulation result, that is, which parameters are to be varied so as to find the optimum solution of the simulation. It is known that input parameters have different influence on the simulation result; therefore, it is necessary to establish which parameters have the strongest influence.

## 3.1 The basic characteristics of the program package Virtual CRASH

The program package Virtual CRASH was used in this paper to analyse the influences of the collision parameters on the simulation result. This package was specially created and based on the measurable physical data in order to support the expert simulation of the car accident being performed. All the versions of Virtual CRASH have different models, the most important being the collision model and the trajectory model [13].

The virtual CRASH collision model is an impulse-momentum model. Linear momentum and angular momentum are conserved, and energy loss is accounted for with a coefficient of restitution. Sliding impacts are handled with an inter-vehicle contact plane and coefficient of friction. Based on the inputs, a crash impulse vector is calculated (*Figure 1*), which causes each vehicle to sustain a linear and angular velocity change.

The virtual CRASH trajectory model, as well as PC-Crash's trajectory model, is based on a discrete time-forward kinetic simulation of vehicle dynamics. Vehicle acceleration is calculated for each time step based on motion inputs from the previous time step, tire-ground
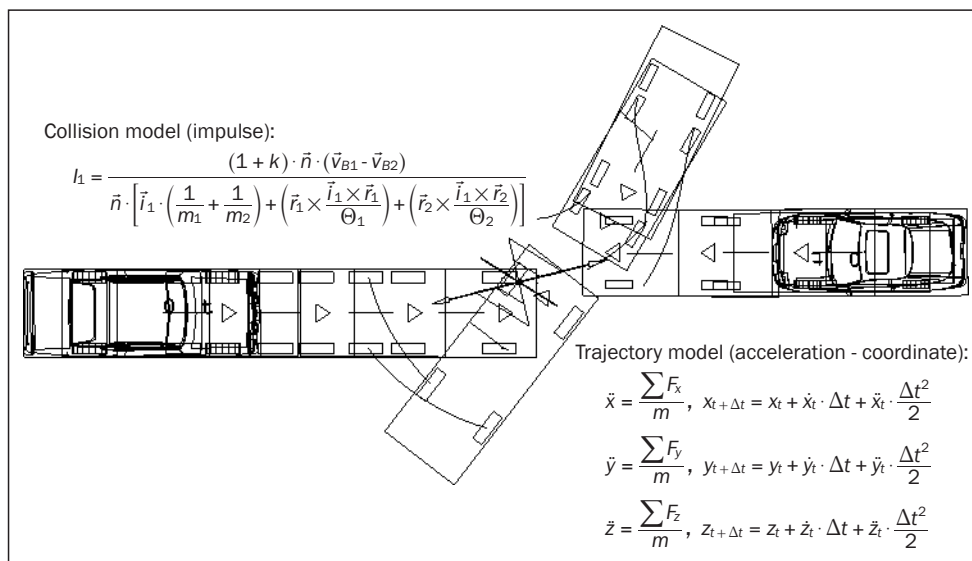


Collision model (impulse):

$$I_1 = \frac{(1+k) \cdot \vec{n} \cdot (\vec{v}_{B1} - \vec{v}_{B2})}{\vec{n} \cdot \left[ \vec{I}_1 \cdot \left( \frac{1}{m_1} + \frac{1}{m_2} \right) + \left( \vec{r}_1 \times \frac{\vec{I}_1 \times \vec{r}_1}{\Theta_1} \right) + \left( \vec{r}_2 \times \frac{\vec{I}_1 \times \vec{r}_2}{\Theta_2} \right) \right]}$$

Trajectory model (acceleration - coordinate):

$$\ddot{x} = \frac{\sum F_x}{m}, \quad x_{t+\Delta t} = x_t + \dot{x}_t \cdot \Delta t + \ddot{x}_t \cdot \frac{\Delta t^2}{2}$$

$$\ddot{y} = \frac{\sum F_y}{m}, \quad y_{t+\Delta t} = y_t + \dot{y}_t \cdot \Delta t + \ddot{y}_t \cdot \frac{\Delta t^2}{2}$$

$$\ddot{z} = \frac{\sum F_z}{m}, \quad z_{t+\Delta t} = z_t + \dot{z}_t \cdot \Delta t + \ddot{z}_t \cdot \frac{\Delta t^2}{2}$$

*Figure 1 - Collision and trajectory model*

forces, and other forces. Steering and individual wheel brake or acceleration factors are taken into account. Weight transfer due to roll, pitch and yaw motions is taken into account. Alongside these two models, this program contains other models as well, such as the trailer model, the multibody model and other additional models.

On the basis of individual models or on the basis of their combination, the motion of cars, pedestrians, cyclists, freight vehicles, etc. can be reliably defined before, during or after a collision. All the movements of the collision participants can be calculated within the simulation with the positive (forward) or the negative (backward) time step.

## 4. RESEARCH PROCEDURE

In order to determine the influence of certain input parameters on car collision simulation and the validity of the results, the simulation of collisions with the known values of input parameters was done in the program package Virtual CRASH. For the needs of the analysis, the crash test results were used, taken from previous research studies [14]. These tests are RICSAC (Research Input for Computer Simulation of Automobile Collisions) and JARI (Japan Automobile Research Institute).

The reason for choosing RICSAC collisions for carrying out certain analyses in this paper is that these collisions were used for testing many program packages (SMAC, CRASH, PC-CRASH, Virtual CRASH) for modelling car collisions. RICSAC and JARI tests were used for studying a few collision configurations which represent typical cases of traffic accidents in the real surroundings, and they included head-on collisions, lateral collisions and rear-end collisions. During the test, each vehicle was equipped with the measuring instruments for tracking certain parameters in the function of time: triaxial accelerometer set on the partition (the vehicles position, velocity and acceleration), linear potentiometer set on the steering wheel (angles of the steering wheels), electric tachometers on at least three wheels (rolling speed), a recorder for recording data, at least ten fast cameras, including two handheld cameras for recording each test, marker paint sprayed from nozzles (two per vehicle) for directly identifying each vehicle's path. Post-collision measurements included: the wheels position at the point of collision and on the stopping position of the vehicle, location of the debris, traces of braking, skidding, scratching, dispersed liquid, vehicle trajectory (colour marker), deformation on the vehicles [15].

For the simulation of selected collisions from RICSAC and JARI crash tests, the program package Virtual CRASH was used. The research study covered varying certain input parameters in the simulation of real

crash tests and measuring the value of error. For each simulation, technical characteristics of vehicles, collision velocities and braking data of each wheel of the vehicle after the collision were entered. The vehicles were positioned on the scanned beat maps of situation plans, which show the collision positions of the vehicles, tire traces and stopping positions. The aim was to get the stopping positions of the vehicles in the simulation by means of input values measured in tests, the same as those drawn on situation plans, that is, to minimise the error between the real collision and the simulation. After that, simulation input varying was carried out in relation to the tests values, in order to establish to which extent certain input change influences the output, that is, the error value in the simulation in relation to the real situation.

Similar research procedures in car collision processes have been applied so far. Spit has done PC-CRASH validation during three-month training in TNO Accident Analysis group. Well-documented crash tests of lateral car collisions done by TNO crash laboratory have been selected for validation [16].

## 5. PROGRAM VIRTUAL CRASH APPLICATION IN COLLISION ANALYSIS

For the analysis, a simulation has been carried out, where all the physical values significant for the collision process have already been known, and these are four crash tests RICSAC and three crash tests JARI. On this occasion, the same collisions used for the program PC CRASH validation by Moser and Cliff have been analysed [14], so that the vehicle stopping positions obtained by simulation in PC CRASH are shown in the pictures.

The vehicles which participated in the collision are marked as vehicle 1 and vehicle 2. Vehicle 1 is marked in blue in the pictures and it is the vehicle which hits (bullet), and vehicle 2 is red and that is the vehicle which is hit in the collision (target). The best simulation results regarding velocity and stopping position had the smallest error regarding velocity and stopping position. The real vehicle stopping positions are shown in black rectangles, and the real vehicle contours show the stopping positions obtained in Virtual CRASH simulation. For comparative analysis, the stopping positions obtained in PC-CRASH simulation are shown in the form of blue and red rectangles, as in [14].

Example number 1 (RICSAC 12) shows the head-on collision, with overlapping frontal parts of the vehicles of about 70%. The primary contact has been made between the frontal left sides of the cars, where vehicle 1 is slanted in relation to vehicle 2 for 13o. The error in vehicle stopping positions in the performed simulation is 12%, in collision velocities 0.4% and 6.3% for vehicles 1 and 2, respectively.
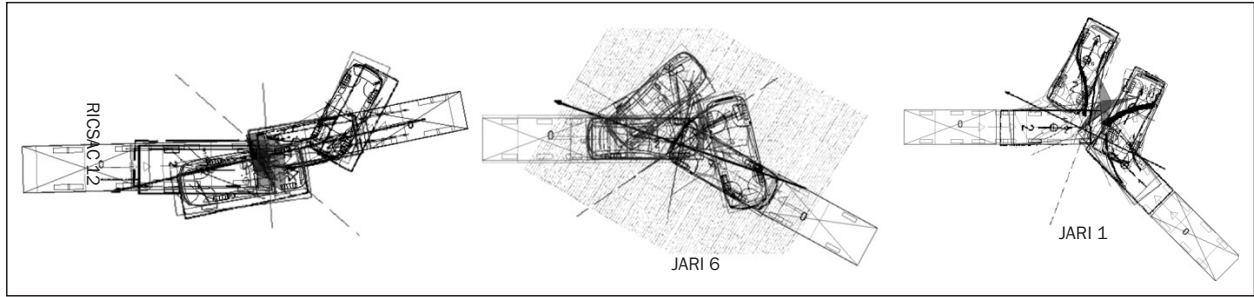
*Figure 2 - Analysed examples of crash tests number 1, 2, 3*
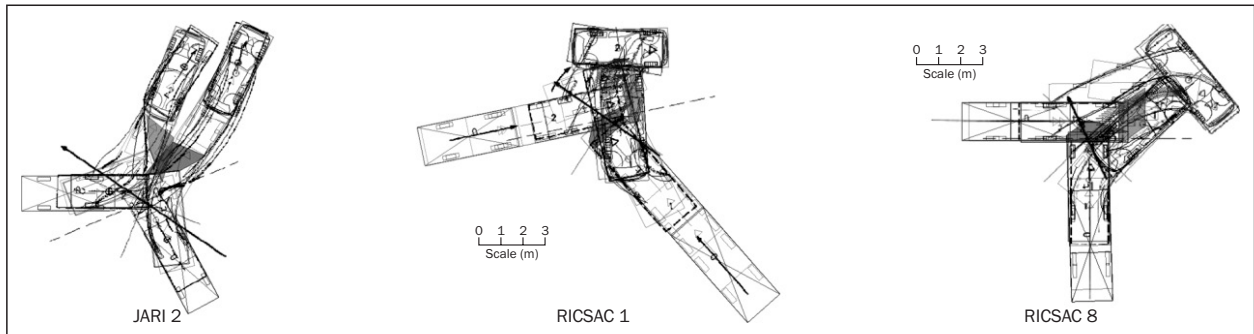


*Figure 3 - Analysed examples of crash tests number 4, 5, 6*

Example number 2 (JARI 6) shows head-on, oblique, eccentric collision with slight vehicle motion in the post-collision phase, due to the front wheels blocking after being damaged. The error in vehicle stopping positions in the performed simulation is 11%, the error in collision velocities 0.4% and 1.6% for vehicles 1 and 2, respectively.

Example number 3 (JARI 1) shows the head-on collision at the angle of about 45° where the vehicles stopped nearby the collision place. The error in vehicle stopping positions in computer simulation is 6%, the error in collision velocities is -1.2% and -3.4% for vehicles 1 and 2, respectively.

Example number 4 (JARI 2) shows the head-on car collision at an angle of about 60° with longer paths for vehicles stopping. The error in vehicle stopping positions is 3%, the error in collision velocities is 1% and 0% for vehicles 1 and 2, respectively.

Example number 5 (RICSAC 1) shows the lateral cars collision at an angle. The error in vehicle stopping positions in the simulation is 10%, the error in collision velocities is -12.2% and -13.8% for vehicles 1 and 2, respectively.

Example number 6 (RICSAC 8) shows the lateral cars collision at the right angle, with the continuous inter-vehicle contact. The error in vehicle stopping positions in the simulation is 4%, the error in collision velocities is -13.2% and 5.3% for vehicles 1 and 2, respectively.

Example number 7 (RICSAC 3) shows a collision, that is, hitting a stopped car. The error in vehicle stopping positions in simulation is 2%, the error in collision velocities is 5.3% and 0% for vehicles 1 and 2, respectively.

In this paper, for the evaluation of the total error in the trajectory, that is, trajectory error $\delta_T$, the model given by W. Cliff and A. Moser was used [14], and it is based on the smallest square method:

$$\delta_T(\%) = \sqrt{\frac{\sum_{i=1}^{n}(w_i \cdot \delta_i)^2}{\sum_{i=1}^{n} w_i^2}} \cdot 100 =$$

$$= \sqrt{\frac{(w_{xy} \cdot \delta_{xy})^2 + (w_{\psi} \cdot \delta_{\psi})^2}{w_{xy}^2 + w_{\psi}^2}} \cdot 100 \qquad (1)$$
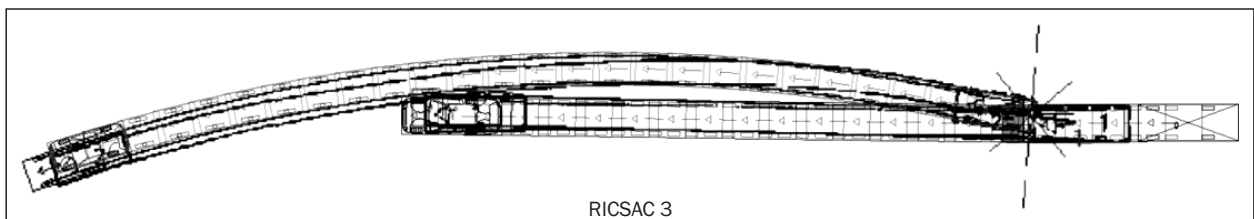


*Figure 4 - Analysed example of crash test number 7*

*Table 1 shows some of the collision parameters in crash tests and those obtained in simulation.*

| Example | Test number | Vehicle number | Collision velocity km/h | | Post-collision velocity (km/h) | | ΔV (km/h) | | *Kr*\* | Friction\* |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Test | Virtual CRASH | Test | Virtual CRASH | Test | Virtual CRASH | | |
| 1 | RICSAC 12 | 1 | 50.7 | 50.9 | 14.0 | 14.9 | 64.5 | 65.8 | 0.10 | 0.46 |
| | | 2 | 50.7 | 53.9 | 11.7 | 12.7 | 42.5 | 45.7 | | |
| 2 | JARI 6 | 1 | 50.3 | 50.5 | 10.0 | 9.7 | 54.0 | 54.4 | 0.13 | 0.51 |
| | | 2 | 49.8 | 49.0 | 17.0 | 16.2 | 50.0 | 50.0 | | |
| 3 | JARI 1 | 1 | 49.9 | 49.3 | 17.0 | 16.3 | 48.0 | 47.8 | 0.15 | 0.46 |
| | | 2 | 49.6 | 47.9 | 22.0 | 21.2 | 48.0 | 47.4 | | |
| 4 | JARI 2 | 1 | 49.5 | 50.0 | 25.0 | 25.3 | 38.0 | 38.6 | 0.15 | 0.46 |
| | | 2 | 49.3 | 49.3 | 26.0 | 26.1 | 42.0 | 42.1 | | |
| 5 | RICSAC 1 | 1 | 31.9 | 28.0 | 17.7 | 11.2 | 19.6 | 18.5 | 0.18 | 0.46 |
| | | 2 | 31.9 | 27.5 | 20.1 | 20.9 | 25.1 | 26.7 | | |
| 6 | RICSAC 8 | 1 | 33.4 | 29.0 | 19.0 | 13.3 | 24.6 | 20.6 | 0.25 | 0.46 |
| | | 2 | 33.4 | 29.0 | 25.3 | 26.8 | 17.2 | 19.6 | | |
| 7 | RICSAC 3 | 1 | 34.2 | 36.0 | 18.8 | 21.1 | 15.3 | 15.1 | 0.11 | 0.46 |

*\*no test data available*

*Table 2 - Analysed input*

| Collision parameter | Variation limits | Collision parameter | Variation limits |
|---|---|---|---|
| 1. vehicle movement direction | ±4˚ | 11.centre of gravity position from front axle of vehicle 2 | ±0.15m |
| 2. slowing down the vehicle | ±1 m/s$^2$ | 12.intervehicle friction coefficient | 0.8-1.2 |
| 3. contact plane angle | ±15˚ | 13.vehicle masses inversely proportional | ± 140kg |
| 4. collision angle | ±6˚ | 14.vehicles masses directly proportional | ±100kg |
| 5. centre of gravity height-vehicle1 | 0.40-0.68m | 15.penetration-compression time | 0.02-0.05s |
| 6. centre of gravity height-vehicle2 | 0.40-0.68m | 16.collision velocities | ±20% |
| 7. collision place in transverse dir. | ±0.30m | 17.collision point in direction of X axis | ±0.24m |
| 8. collision place in longitudinal dir. | ±0.50m | 18.collision point in direction of Y axis | ±0.24m |
| 9. restitution coefficient | ±30% | 19.collision point in direction of Z axis | 0.4-0.6m |
| 10. centre of gravity position from front axle of vehicle 1 | ±0.15m | 20.overlapping width | ±1.0m |

In the previous equation (1) the weight parameters are marked by $w_i$, for defining influence of each of the errors ($\delta_{xy}$ distance error, that is, in coordinates and $\delta_\psi$ angular error). Values $w_{xy} = w_\psi = 100\%$ are taken for their values. In this way the influences of the distance and angle error are equated.
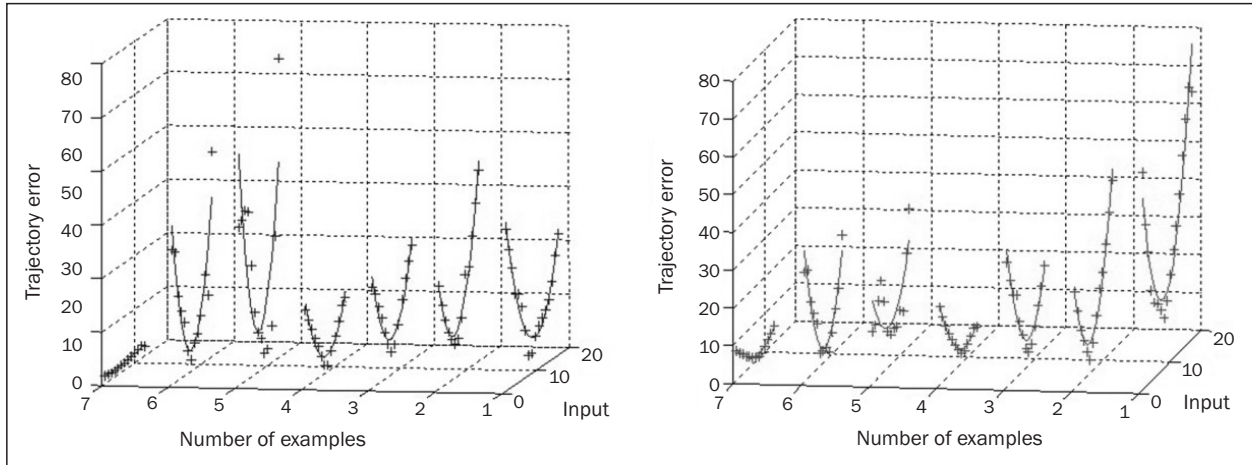
In the simulations of vehicle collisions in any of the programs, there is a certain error in the obtained results in relation to the real values. The error is a consequence of different hypotheses and simplifications included in the program and the operator inability to define the model which completely reflects the real collision by selecting certain parameters.

## 6. INPUT PARAMETERS VARIATION

For determining the input parameter influences on the simulation error the variation of twenty input pa-

rameters has been done, in certain range and for every input the error has been determined in the values of output results. In total 1,800 variations have been done with the limits in accordance with the recommendations [17] and the researcher's estimate. On the basis of the calculated mean values of the errors pareto diagrams have been formed showing the first ten most influential parameters on the output result of the simulation. Since there is a large number of numerical data and the mathematical problem, a special tool has been made for this analysis [18] in MATLAB. The parameters varied in the simulations are shown in *Table 2*.

Graphic results of errors obtained in computer simulation have been approximated by the second order parabola (*Graph 1*). Ordinal numbers of crash tests are shown on the abscissa, parameter values are on the ordinate and the trajectory error in % on the applicate. Analogous to the colours of vehicles in the simulation

*Graph 1 - Error changes in the function of vehicle movement directions [18]*
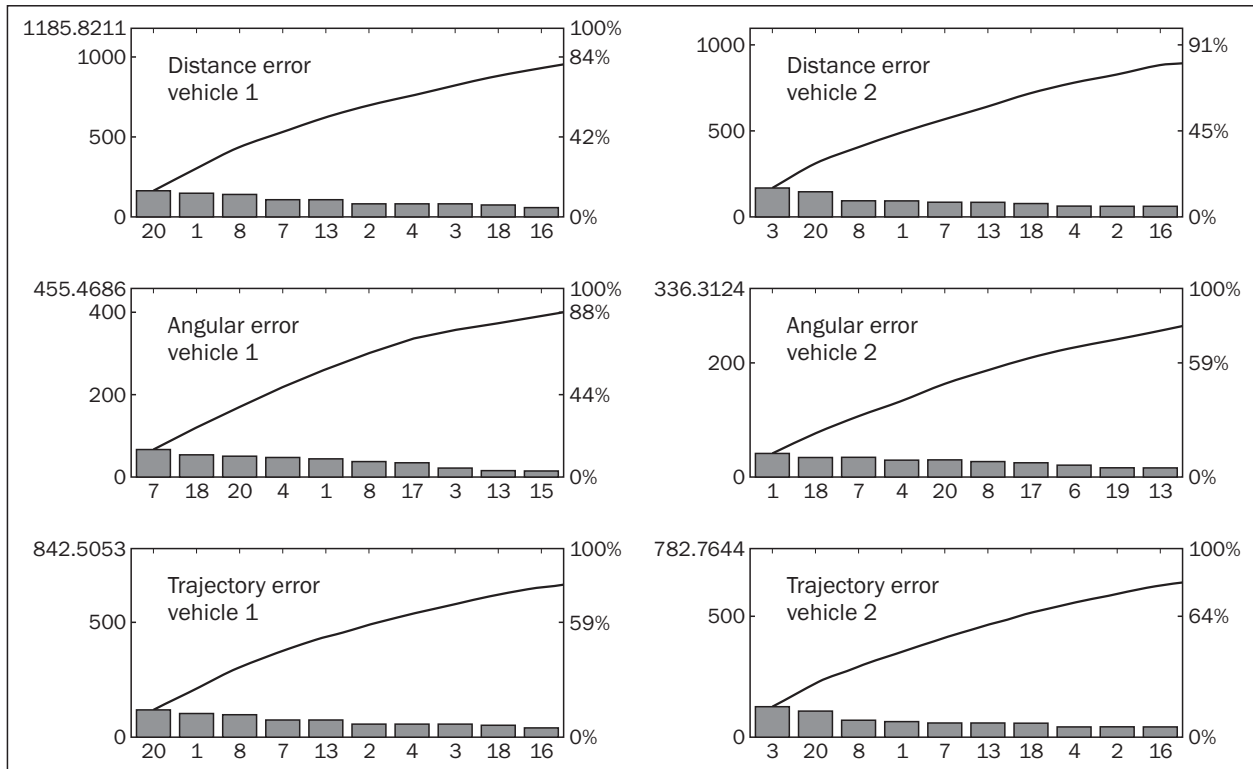
(the bullet vehicle is blue, the target vehicle 2 is red), blue is used in the graph referring to vehicle 1, and red in the graph referring to vehicle 2.

The previous graph shows the errors in simulation depending on the change of one input – vehicle motion direction (Y) on the trajectory error. The same procedure has been applied to the influence of all other 19 input parameters on the distance and the angular error.
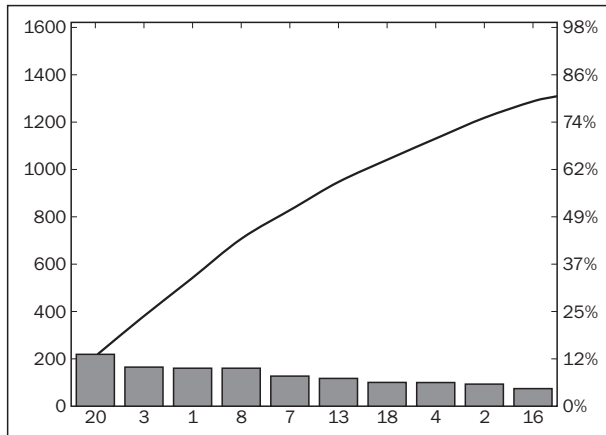
## 7. ANALYSIS OF INPUT PARAMETERS INFLUENCE ON THE SIMULATION ERROR

Since the total errors obtained in computer simulation of the analysed crash tests have been between 2 and 12%, it was necessary to reduce the results at equal beginning conditions, so as to have comparable results. For that reason normalisation has been performed, in such a way that for the optimum computer simulation of each example the agreed total error is 0%. In this way, all the examples had the same starting conditions in terms of error values. After normalisation, the mean value of all errors occurring during a certain input parameter variation was calculated. Pareto diagrams have been formed in MATLAB software on the basis of mean values of the calculated errors. The parameters influence on errors in all seven examples simultaneously is shown in *Graph 2*. Ten most influential parameters have been separated and shown in pareto



*Graph 2 - The input influence on errors in computer analysis - all 7 examples*

*Graph 3 - Input influence on errors in computer analysis*

diagrams, out of twenty analysed input parameters of collisions. The inputs in the diagram are sorted in descending order so that the first parameter is the one which is the most influential. The ordinal number of input parameters is shown in *Table 2*.

Input influence on distance, angular and trajectory error, parallel to vehicle 1 and vehicle 2 is shown in *Graph 2*. However, all these errors can be observed together, as one error relating to the total trajectory error in the simulation for both vehicles.

*Graph 3* in the form of pareto diagram shows the input influence on the total error in computer simulation for all seven parameters, for both vehicles.

## 8. DISCUSSION OF RESULTS

Analysis results have shown that most parameters which have been the most influential for the trajectory error of vehicle 1, have also been the most influential on the trajectory error of vehicle 2, with possibly different order of influence.

For distance, that is, trajectory errors, those are:
– vehicle movement direction,
– vehicle slowing down,
– contact plane angle,
– collision angle,
– collision point in transverse direction,
– collision point in longitudinal direction,
– vehicle masses inversely proportional,
– collision velocities,
– collision point in the direction of Y axis,
– overlapping width.

The most influential parameters for angular errors are:
– vehicle motion direction,
– collision angle,
– collision point in transverse direction,
– collision point in longitudinal direction,
– collision point in the direction of Y axis,
– overlapping width.

In *Graph 3* it can be noticed that almost 80% of the total error in the computer simulation has been caused by 10 out of the 20 analysed input parameters. The analysis has shown that distance, trajectory and angular error in the simulation are most influenced by:
1. overlapping width (20),
2. contact plane angle (3),
3. vehicle motion direction (1),
4. collision point in longitudinal direction (8),
5. collision point in transverse direction (7),
6. vehicle masses inversely proportional (13),
7. collision point in the direction of Y axis (18),
8. collision angle (4),
9. vehicle slowing down (2),
10. collision velocities (16),

Since the listed parameters are the most influential for the collision simulation accuracy, the program operator has to pay particular attention to determining the parameters as precisely as possible.

## 9. CONCLUSION

In this paper, twenty input parameters have been defined and their influence degree on errors in the simulation procedure in the program Virtual CRASH determined. Real collision simulations done in crash tests, where the largest number of input parameters has been known, have been used for determining which of the input parameters has the biggest influence on the simulation error. After a large number of simulation experiments, the influence of each individual parameter on the error value has been determined. Out of twenty analysed collision parameters, ten have been isolated as the most influential ones. The obtained results can be used with all the programs where the basis of the collision model is Kudlich-Slibar collision model.

This paper results can be useful for the work on programs which do not have automatic optimiser of collision. The paper findings can facilitate researchers their work in vehicle collision simulation and make it more efficient. Defining the most influential collision parameters can facilitate and shorten the time of simulations in program packages which have the optimiser as well. Variation of only the most influential parameters in the optimisation procedure can reduce the number of iterations, shorten the simulation time and eventually reduce errors.

Other parameters which are not the ten most influential ones can also have a significant influence on the collision modelling. It is most difficult to estimate the restitution coefficient, inter-vehicle friction coefficient and compression duration. For this reason, final iterations should be checked in terms of their assumed values and if necessary they should be calibrated.

Further research should study the sensitivity of the most influential parameters. Besides, it would

be useful to define the limit values of collision input parameters, and not to accept values beyond them, considering that otherwise simulation errors would be significant.

Dr **VUK BOGDANOVIĆ**
E-mail: vuk@uns.ac.rs
Univerzitet u Novom Sadu, Fakultet tehničkih nauka
Trg Dositeja Obradovića 6, 21000 Novi Sad, Srbija
Mr **NENAD MILUTINOVIĆ**
E-mail: nenadmilu@yahoo.com
Visoka tehnička škola strukovnih studija
Kosovska 8, 34000 Kragujevac, Srbija
Dr **SVETOZAR KOSTIĆ**
E-mail: sasakostic49@gmail.com
Mr **NENAD RUŠKIĆ**
E-mail: nruskic@uns.ac.rs
Univerzitet u Novom Sadu, Fakultet tehničkih nauka
Trg Dositeja Obradovića 6, 21000 Novi Sad, Srbija

*REZIME*

*ISPITIVANJE UTICAJA ULAZNIH PARAMETARA NA REZULTAT SIMULACIJE SUDARA VOZILA*

*Sudari automobila su složeni procesi koji su određeni velikim brojem različitih parametara. Razvoj kompjuterskih programa za simulaciju olakšao je postupak analize i rekonstrukcije sudara kao i mogućnost sagledavanja uticaja različitih parametara na sudarne procese, što klasičnim metodama nije bilo moguće. Kvalitet rezultata simulacije i rekonstrukcije sudara izražava se greškom koja se određuje na osnovu odstupanja zaustavnih pozicija vozila dobijenih simulacijom od utvrđenih zaustavnih pozicija vozila u realnim sudarima. Poznavanje uticaja parametara sudara na simulacionu grešku omogućava razvijanje pouzdanijih modela za automatsku optimizaciju sudarnog procesa i smanjenje broja iteracija u postupku rekonstrukcije sudara. U okviru ovog rada izvršena je analiza i klasifikacija različitih parametara sudara prema stepenu uticaja na grešku u procesu simulacije u programskom paketu Virtual CRASH. Varijacijom dvadeset parametara sudara na primeru sedam crash testova analiziran je njihov uticaj na distancionu, trajektorijsku i ugaonu grešku i izdvojeno je deset parametara (položaj težišta od prednje osovine voz. 1, koeficijent restitucije, mesto sudara u poduž. pravcu, visina težišta voz. 2, visina težišta voz.1, ugao sudara, ugao sudarne ravni, usporenje vozila, pravac kretanja vozila) sa najvećim stepenom uticaja.*

*KLJUČNE REČI*

*sudar, vozila, parametri, simulacija, greška*

## LITERATURE

[1] **Day, T.D.**, **Hargens, R.L.**: *Application and Misapplication of Computer Programs for Accident Reconstruction*, SAE Paper, 890738, 1989

[2] **Batista, M.**, **Magister, T.**, **Bogdanović, L.**: *Computer Based Road Accident Reconstruction Experiences*, Promet Traffic&Transportation, Vol. 17, 2005, pp. 65-75.

[3] **Krulec, R.**, **Batista, M.**: *User interface for the smac traffic accident reconstruction program*, Promet Traffic&Transportation, Vol. 15, 2003, pp. 375-380

[4] **Day, T.D.**: *An Overview of the EDSMAC4 Collision Simulation Model*, SAE Paper 1999-01-0102, 1999

[5] http://www.mchenrysoftware.com (accessed 26.02.2011).

[6] **Moser, A.**, **Steffan, H.**: *Automatic Optimisation of Pre-Impact Parameters Using Post-Impact Trajectories and Rest Positions*, SAE Paper 980373, 1998

[7] **Spit, H.H.**: *Evaluation of PC Crash as a tool for professional traffic accident research and reconstruction*, TNO report 00.OR.BV.2712.1/HHS, thesis teaching practice University of Technology Eindhoven, 2000

[8] **Spit, H.H.**: *MC-CRASH Probability distributions in traffic accident analysis*, TNO, 2002

[9] **Papić, Z.**, **Bogdanović, V.**, **Ruškić, N.**: *Značaj kompjuterske vizualizacije saobraćajne nezgode u sudskom postupku*, IX Simpozijum sa međunarodnim učešćem - Prevencija saobraćajnih nezgoda na putevima 2008, Novi Sad, 2008, Proceedings, pp. 247-252

[10] **Rotim, F.**: *Elementi sigurnosti cestovnog prometa Kinetika vozila*, Vol. 2, Faculty of Transport and Traffic Sciences, University of Zagreb, 1991

[11] **Batista, M.**, **Zovak, G.**: *Restitution model of two-car collinear collisions*, Promet Traffic&Transportation, Vol. 19, 2007, pp. 1-6

[12] **David, R.**: *A Generalized Two-Dimensional Model to Reconstruct the Impact Phase in Automobile Collisions*, Master thesis, Department of Mechanical Engineering, Brigham Young University, 2007

[13] **Melegh, G.**, **Gabor, V.**: *Virtual CRASH*, Technical Manual, Budapest, 2007

[14] **Cliff, W.E.**, **Moser, A.**: *Reconstruction of Twenty Staged Collisions with PC-Crash's Optimizer*, SAE 2001-01-0507, 2001

[15] **Jones, S.**, **Baum, S.**: *Research Input for Computer Simulation of Automobile Collisions*, Vol. IV: Staged Collision Reconstructions, DOT HS-805 040, NHTSA, Washington, 1978

[16] **Tomasch, E.**: *Accident Reconstruction Guidelines*, University of Technology, Graz, 2004

[17] Datentechnik, S.: *PC-CRASH Operating Manual Version 8.2*, Linz, 2008

[18] **Milutinović, N.**: *Ispitivanje mogućnosti primene i pouzdanosti korišćenja softvera za simulaciju u ekspertizama sudara automobila*, Master thesis, Fakultet tehničkih nauka, Novi Sad, 2008