An expert system for vehicle accident reconstruction

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Abstract. The paper presents the capabilities of the developed expert system for vehicle accident reconstruction. The system determines converted energy for each vehicle, post-collision and pre-collision vehicel speeds, vehicle braking deceleration, the times in the braking process and total stopping distance. This system provides an opportunity to investigate the impact of various parameters at vehicle accident reconstruction. The developed expert system significantly reduces the time for the preparation of the expertise and the admission of errors. It can be used in expert practice and training.

1. Introduction

Bulgaria is one of the countries in the European Union with the highest number of deaths in road accidents, according to the population [1].

Under the Law on the Judiciary to investigate the causes and the possibilities for prevention of traffic accidents expertise are appointed for the needs of the court process. It is impossible to have quality justice without quality expertise. This is because many of the cases are dealt with primarily on the basis of the expert reports. Poor expertise leads to poor justice.

In Bulgaria for each judicial district compile lists of specialists approved experts. The procedure for inclusion in these lists of specialists qualified as experts is regulated by the Ministry of Justice.

Unfortunately lists of experts shall be approved by the Commission which includes only judges and prosecutors – persons who do not have a technical education. These Commissions have no knowledge and cannot assess the technical competence and ability of the candidates for experts. Moreover, there is no requirement for licensing experts in Bulgarian legislation. All of this can lead to the production of low-quality expertise.

In order to increase the quality of the expertise, the Rousse University team has developed a vehicle accident reconstruction expert system based on the energy method. This article presents the possibilities and the way this expert system works. There are no suitable software applications in Bulgaria that can be used by the experts, which is a further reason for doing so.

2. Mathematical model

According to [2, 3, 4, 5, 6] one of the most important issues in the investigation and analysis of road accidents is the determination of vehicle speeds and the stopping distance.

In practice, experts use different methods [2, 7, 8, 9, 10, 11, 12, 13, 14, 15] for reconstruction of vehicle collision accidents. Each has its advantages and disadvantages. In some cases, one method is better, and in others - another.

In Bulgaria, one of the commonly used method for determining the vehicles speed in accidents is the energy method. This method is to use six points damage profile depth to determine the dimensions of the crush [16, 17, 18, 19, 20]. Under this method, the converted energy $E$ for each vehicle during the impact is calculated as follows:
The change in vehicle velocity $\Delta V$ can be written as in equation:

$$\Delta V_{1,2} = \left[ \frac{2m_{1,2}(E_{1} + E_{2})}{m_{1,2}(m_{1} + m_{2})} \right]^{1/2}, \text{m/s}$$

where $m_{1}$ is mass of vehicle 1; $m_{2}$ - mass of vehicle 2; $E_{1}$ - converted energy of vehicle 1; $E_{2}$ - converted energy of vehicle 2.

The post-collision velocities $u$ can be written as in equation:

$$u_{1,2} = \left[ 2g(\varphi_{1,n}S_{1,n} + \varphi R \omega) \pm V_{(\omega)}^{2} \right]^{1/2}, \text{m/s}$$

where $\varphi_{1,n}$ is coefficients of friction; $S_{1,n}$ - distance travelled by the vehicle after the collision; $g$ - gravity acceleration; $R$ - radius of vehicle rotation, m; $\omega$ - rotation of the vehicle after the collision, rad; $V_{(\omega)}$ - loss (acquired) speed of vehicles after impact.

The radius of vehicle rotation can be calculate by the following equation:

$$R = \left[ \left( \frac{L_{b}}{2} \right)^{2} + \left( \frac{B_{k}}{2} \right)^{2} \right]^{1/2}, \text{m}$$

where $L_{b}$ is vehicle wheelbase; $B_{k}$ - vehicle track.

The pre-collision velocity can be written as in equation

$$V_{1,2} = \left( \Delta V_{1,2}^{2} - u_{1,2}^{2} \sin^{2} \theta_{1,2} \right)^{1/2} + u_{1,2} \cos \theta_{1,2}, \text{m/s}$$

where $\theta_{1,2}$ is angles between the velocities before and after impact.

To analyze accidents and determine the possibility of their prevention by drivers it is necessary to calculate the stopping distance. Total stopping distance can be calculate by the following equation:

$$D = tV + \frac{V^{2}}{2a}, \text{m}$$

where $t$ is total start time for braking, s; $V$ - vehicle speed, m/s; $a$ - braking deceleration, m/s$^{2}$.

The braking deceleration for a longitudinal slope of road is calculated as follows

$$a = \left( \frac{\varphi \cos \beta \pm \sin \beta}{c_{e}} \right) g, \text{m/s}^{2}$$

where $\beta$ is slope of road angle, deg. $c_{e}$ - coefficient of efficiency. "plus" sign - slope up; "minus" sign - slope down.

The braking deceleration for a horizontal road is calculated as follows

$$a = \frac{\varphi g}{c_{e}}, \text{m/s}^{2}$$
The total start time for braking is calculated as follows
\[ t = t_d + t_v + 0.5t_i \; s \]  \hspace{1cm} (9)
where \( t_d \) is driver reaction time, \( s \); \( t_v \) - vehicle reaction time, \( s \); \( t_i \) - time for increase the braking deceleration, \( s \).

3. Expert System
In the field of transport and traffic safety various calculation tools are used. Unfortunately they have a number of limitations, such as: there is no possibility of entering specific values for different parameters; do not provide the ability to select pre-set reference data; do not inform the user about incorrect data entered etc. [11, 21 - 24]. Because of these features, they are not suitable in expert practice.

The main window of the energy method based expert system for vehicle accident reconstruction is presented in figure 1.

![Figure 1. Main window of expert system for Vehicle Accident Reconstruction.](image)

The expert system is developed by means of the object-oriented and platform independent programming language – Java [25]. It makes possible for the application to run on every computer platform that has Java Virtual Machine installed on it both as a standalone application and as an applet integrated into a web page and available on the Internet.
The expert system consists of six panels in a scrollable window. The first one (figure 1, position 1) is for calculation of the transformed kinetic energy (1) and the change in vehicles speeds at impact (2), the second (figure 1, position 2) – for the post-collision velocities (3) and the third (figure 1, 3 positions) – for the pre-collision velocities (4). The fourth panel is for determination of the braking deceleration, the fifth – for determination of the total time and last sixth panel is for the determination of the total stopping distance.

3.1. Functioning of the Expert System
After starting the system the user fills in panel 1 the measured values for damage profile depths in fields d₁ - d₆, the masses of vehicles m, damage profile width W, crash coefficients A and B, the angle α between the normal to the damage profile surface and impact pulse vector and clicks the "Calculate" button. If it turns out that in some fields are entered non-numeric values a warning message appears stating that the value of the specified field is not numerical (figure 2, position 1).

![Figure 2. Warning message for a not numerical value.](image)

After checking for not numerical values, starting from the left margin of the top row and ending with the right margin of the bottom row another checking is performed that determines if any value falls within the pre-set space of values for it or is equal to a value of a number of acceptable values. If some value is unacceptable (figure 3, position 1) a message about it appears.

![Figure 3. Warning message for unacceptable value.](image)

If the user clicks the "No" button the entered in the field value is deleted (figure 4, position 1) and a new message appears (figure 4, position 2).

![Figure 4. Warning message for a new value.](image)
If the user presses the "Yes" button the entered in the field value is reserved and the message "The value of $d_0$ is accepted. Press "Calculate" to continue". So the entered value, though not belonging to a preset space of values for it, is accepted and it will be used in the upcoming calculations.

In order to determine the speeds of the vehicle after the collision in panel 2 (figure 1) it is necessary to fill in coefficients of friction $\varphi$ and corresponding movements of the vehicles $S$, wheelbase $L_0$, and rear track $B_k$ of the vehicles and rotation of the vehicles after the collision $\omega_0$.

There is a possibility to determine the speed when driving on three surfaces with different coefficients of adhesion. The impact of the lost or acquired velocity of the vehicles after the collision is taken into account (toggle button lost/acquired). Described above checks for incorrect or non-numerical values are made in this panel as well.

At impact speeds of the vehicles are calculated in panel 3. For this purpose it is necessary to fill in the angles between the velocities of the vehicles before and after the impact $\theta$ (figure 1). The other values, necessary for determining the speeds, are automatically generated from the calculations in the previous two panels of the system.

The fourth panel provides controls for determining the braking deceleration, indicating the presence and magnitude of road slope as well as the coefficients of friction and efficiency. To determine the presence and type of road incline, a combo box with three items is used: horizontal, slope up or slope down (figure 5, position 1). In the slope size field, a value is selected or entered, and this is only possible for a slope road (figure 5, position 2). Sometimes, in expert practice, the friction and efficiency coefficients must be determined experimentally by different methods and tools. The corresponding values are set in editable combo boxes.

![Figure 5. A general view of the fourth panel.](image)

When the user clicks the “Calculate” button, the braking deceleration value is calculated and displayed in a non-editable text field (figure 5, position 3). Then the controls for setting the values of the values with which the braking deceleration is calculated become inactive. To calculate the braking deceleration with other values the user clicks the "New calculation" button, where the braking deceleration value is replaced by a dash (-), and the "Calculate" button and the controls become active.

To determine the total time, the controls on the fifth panel are used. They are editable combo boxes. The user can choose from a set of predefined values or can input her/his own values for driver and vehicle reacting times and the time for increase the braking deceleration. The total time value is calculated and displayed after pressing the Calculate button. Then the fields become non-editable, and the button changes to "New Calculation".

In the last sixth panel, there is only the "Calculate" button and two text fields that display the values for the stopping distances for both vehicles.

Panels 4, 5 and 6 also provide a check for incorrectly entered or missing values as well as for values beyond the predefined limits. For each established inaccuracy, the expert system shall display the appropriate alert message. This significantly reduces the possibility of making mistakes.

3.2. Realization of the described functionality

For each panel there is an array for correctness of entered data. Each element of this array corresponds to the value entered in a particular text field. At the beginning all elements of the array are initialized to 0, which corresponds to the incorrect data. At every click of the "Calculate" button its elements are reset. Then the data in each field is evaluated and if it’s value is numerical, to the corresponding element in the array is assigned 1. Then the elements of the array are checked from the beginning to
the end and at first meeting of an element showing a non-numerical value, i.e. 0, a message that in the relevant field is introduced non-numerical value appears. After entering a new value these tasks are performed again. This continues until in all text fields there are only numerical values. Then entered in each field value is checked for belonging to a predetermined range of acceptable values. When the checking comes to a value that is not in the preset interval a panel with a message for confirmation of the value appears. If the value is accepted it is stored in an array for accepted values and is noted in an array for acceptable values. It does not matter that the value is not in the predefined interval or set of values. So at the end in all fields there are acceptable values or values, that are accepted explicitly for correct.

To determine the content of the warning dialogues, a one-dimensional array with 3 elements is used. The first element corresponds to the value for the braking deceleration, the second – to the total time and the third - to the pre-collision velocity. Each element can be equal to 1 if the corresponding value is determined and 0 if it is not. When the values of all three elements are equals to 1, the stopping distance can be calculated. Otherwise, a warning message appears indicating which value has not yet been determined.

The developed expert system for determining speeds at impact between vehicles can be used for a strike of a vehicle in a solid object (tree, pillar, wall, etc.) as well. The system reduces significantly the time for determination of the speeds and allows to determine the influence of various parameters on final results. The system prevents errors in the calculation, thus contributing to improving the quality of expert report.

4. Conclusions
The expert system for vehicle accident reconstruction has been developed. The expert system is developed by means of the object-oriented and platform independent programming language – Java. The possibilities and the way of operating are presented. The expert system consists of six panels in a scrollable window. The first one is for calculation of the transformed kinetic energy and the change in vehicles speeds at impact, the second – for the post-collision velocities, the third – for the pre-collision velocities, the fourth panel - for determination of the braking deceleration, the fifth – for determination of the total time and the last sixth panel is for the determination of the total stopping distance.

The system significantly increases the efficiency of experts’ work, reduces the probability of making mistakes and provides opportunity to investigate the impact of various parameters at vehicle accident reconstruction. It can find a real application in the vehicle accident reconstruction and training of experts.

5. References
[1] European Commission. Transport. Statistical pocketbook 2017. Available at: https://ec.europa.eu/transport/facts-fundings/statistics/pocketbook-2017_en.
[2] Lang W, Biao G and Tao C 2013 Vehicle Continuous Collision Accident Reconstruction System Development Procedia - Social and Behavioral Sciences vol 96 pp 1659-1669.
[3] Han I and Kang H 2016 Determination of the collision speed of a vehicle from evaluation of the crush volume using photographs J. Automobile Engineering vol 230(4) pp 479-490.
[4] Lozana J A, Vera C and Félez J 1998 A computational dynamical model for traffic accident reconstruction Int J Vehicle Design vol 19 (2) pp 213-227.
[5] Park S and Han I 2010 Using frontal crush for collision speed estimation in reconstruction analysis of uncertain traffic accidents J Transp Res vol 17(2) pp 49–60.
[6] Zhang X Y, Jin X L and Qi W G 2006 Analysis and reconstruction of the typical traffic accident based on the tire marks J Basic Sci Eng vol 14 (3) pp 418-426.
[7] Bartlett W and Fonda A 2003 Evaluating uncertainty in accident reconstruction with finite Differences SAE Technical Paper No. 2003-01-0489 Warrendale PA.
[8] Brach R M and Matthew R B 2011 Vehicle Accident Analysis and Reconstruction Methods SAE International Second Edition p. 418.
[9] Evtiukov S, Kurakina E, Lukinskiy V and Ushakov 2017 A Methods of Accident Reconstruction and Investigation Given the Parameters of Vehicle Condition and Road Environment Transportation Research Procedia vol 20 pp 185-192.

[10] Han I and Kang H 2016 Three-dimensional crush scanning methods for reconstruction of vehicle collision accidents International Journal of Automotive Technology vol 17(1) pp 91-98.

[11] Kumella A 2016 Building Rail-Vehicle Braking Distance Calculation Tool Using C# Programming Language International Journal of Scientific and Research Publications vol 6 iss 7 pp 162-167.

[12] Lang W and Tao C 2003 Study of the three-dimensional vehicle impact accident simulation and reconstruction system China Journal of Highway and Transport vol 16(4) pp 83-86.

[13] Martínez F, Páez H, Furones A and Sánchez S 2016 Pedestrian-Vehicle Accidents Reconstruction with PC-Crash®: Sensibility Analysis of Factors Variation Transportation Research Procedia Vol. 18 pp 115-121.

[14] Wach W 2016 Calculation reliability in vehicle accident reconstruction Forensic Science International Journal vol 263 pp 27-38.

[15] Wach W and Unarski J 2007 Uncertainty of calculation results in vehicle collision analysis Forensic Science International Journal vol 167 (2) pp 181–188.

[16] Franck H, Franck D 2009 Mathematical Methods for Accident Reconstruction CRC Press - Taylor & Francis Group p. 303.

[17] Gabauer D J and Gabler H C 2006 Comparison of delta-V and occupant impact velocity crash severity metrics using event data recorders Annual Proceedings/Association for the Advancement of Automotive Medicine vol 50 pp 57–71.

[18] Johnson N S and Hampton C G 2014 Evaluation of NASS-CDS Side Crash Delta-V Estimates Using Event Data Recorders Traffic Injury Prevention Journal vol 15 iss 8 pp 827-834.

[19] Pride R, Giddings D, Richens D and McNally D 2013 The sensitivity of the calculation of ΔV to vehicle and impact parameters Accident Analysis & Prevention vol 55 pp 144-153.

[20] Shelby S G 2011 Delta-V as a Measure of Traffic Conflict Severity 3rd international conference on road safety and simulation Indianapolis USA.

[21] Calculate stopping and braking distance Available at: http://www.countcalculate.com/cars-and-speed/stopping-braking-distance.

[22] Calculator for Stopping (Braking) Distance, Acceleration/Deceleration, Speed, Time Available at: https://www.johannes-strommer.com/diverses/pages-in-english/stopping-distance-acceleration-speed/.

[23] Road Safety Week. Available at: http://www.roadsafetyweek.org.uk/stopping-distance-stodalcalte/story_html5.html.

[24] Vehicle Stopping Distance Calculator. Available at: http://www.csignore.com/stopdistcalc.html.

[25] Simon R, Heller P and Ernest M 2001 Complete JavaTM 2 Certification Study Guide SoftPress Ltd p 780.

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