



e-ISSN: 2319-8753 | p-ISSN: 2320-6710

# IJRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**

# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 10, Issue 1, January 2021

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

**Impact Factor: 7.512**

9940 572 462

6381 907 438

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# Dynamic Study of Vehicles Involved in Road Accidents

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**ABSTRACT:** The paper presents the reconstruction of a real road accident, which occurred during the exploitation of the vehicles. There are stabilized the principal specific parameters of the dynamics of the vehicle involved in road accidents. For this purpose, for the reconstruction of road accidents, is used the specialized PC-Crash software. Paper highlights the way of study for avoidance of road accidents, using functions of PC-Crash software. Also, the paper illustrates the way of solving the reconstruction of road accidents in case of uncertainties of different types, in this case, the uncertainties are related to the running path and the reaction time of the driver.

**KEYWORDS:** Motor vehicle, common-rail, electronic control, exhaust gas recirculation.

## I. INTRODUCTION

Vehicle number increase and development of road infrastructure led to traffic intensification and road accident increase. One of the main problems related to the reconstruction of road accidents is to establish dynamics, a requirement always imposed by the judicial parts.

The study of vehicles' dynamics involved in road accidents is characterized by a great complexity and by the existence of numerous parameters, functional and exploitation uncertainties; to these are added the subjective uncertainties of the technical expert. This complexity is due to difficulties, including mathematical description, restoring the kinematics and dynamics of the vehicles as real as possible [1; 2; 3; 4; 7].

## II. ROAD ACCIDENTS RECONSTRUCTION

In the accident there was involved an Audi A6, which was stationary on the sidewalk; the car exceeded the width of the sidewalk with 0.4 m, being out on the road with the same width. During this period, the Skoda vehicle was driving on the road, during which the driver decided to overtake the column of cars, entering the opposite lane and hitting the Audi on the left-back side.

Accident's scene is represented in fig. 1 and it was obtained from PC-Crash software [4; 8], where there are reproduced the initial known positions and final positions of the vehicles.

For the reconstruction of the accident it is used the PC-Crash software. Using the mentioned software, final positions were calculated and it was obtained the result from fig. 2. This diagram shows that the end / stop positions and positions calculated with the PC-Crash program coincide almost completely.

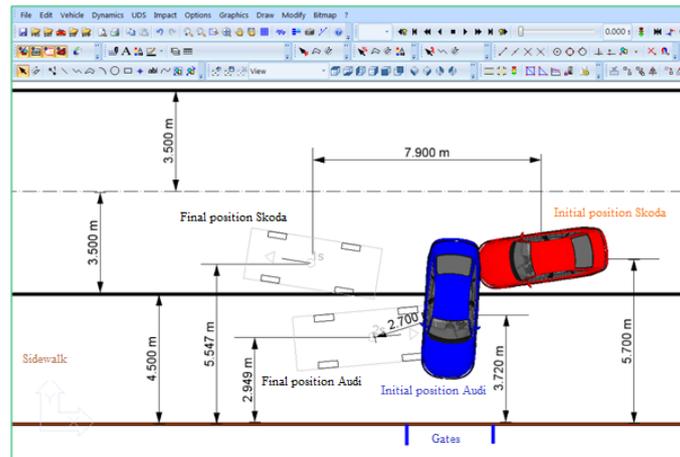


Fig. 1. Accident scene representation

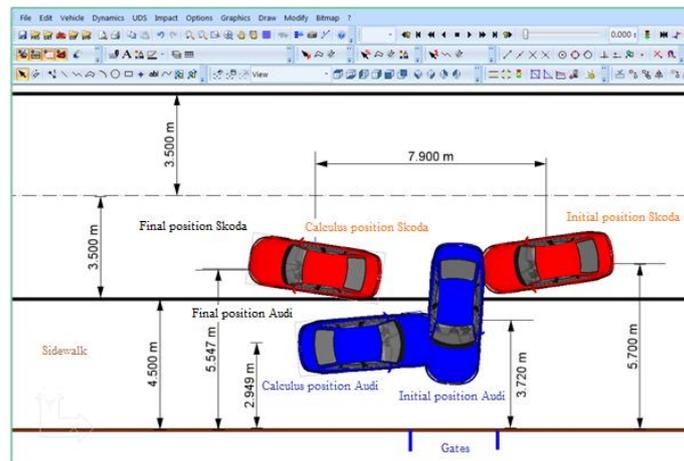


Fig. 2. Final positions of the two vehicles

Separation speeds ( $V_1$  for Skoda,  $V_2$  for Audi) depending on travelled distance after impact, resulting from fig. 1, are  $S_1=7.9$  m and  $S_2=2.7$  m, stabilized with mathematical formula from specialty literature:

$$V = 3.6\sqrt{2\phi gS} \tag{1}$$

where  $\phi$  represents adherence (is adopted  $\phi=0.6$ , for dry asphalt road).

It follows:

$$V_1 = 3.6\sqrt{2\phi gS_1} = 3.6\sqrt{2 \cdot 0.65 \cdot 9.81 \cdot 7.9} = 36.1 \text{ km/h} \tag{2}$$

And respectively:

$$V_2 = 3.6\sqrt{2\phi gS_2} = 3.6\sqrt{2 \cdot 0.65 \cdot 9.81 \cdot 2.7} = 21.1 \text{ km/h} \tag{3}$$

In fig. 3 where there are presented speeds and travelled distances by the two vehicles after impact, results being obtained from the PC-Crash accident simulation software [5; 8].

From fig. 3a results that the impact occurred at time  $t=0.06$  s, when the impact speeds were  $v_1=58.8$  km/h for Skoda and  $v_2=0$  km/h for Audi. Also, the separate speeds were:  $V_1=35.1$  km/h for Skoda and  $V_2=18.2$  km/h for Audi.

It is noticed the closeness of the separation speeds  $V_1$  and  $V_2$  stabilized before, which shows the correctness of the calculations with acceptable errors. Also, the distances traveled and shown in fig. 1, from the scene of the accident, are approximately the same as those calculated with the PC-Crash software from fig. 3b.



Speeds of the two vehicles, travelled distances and some impact parameters

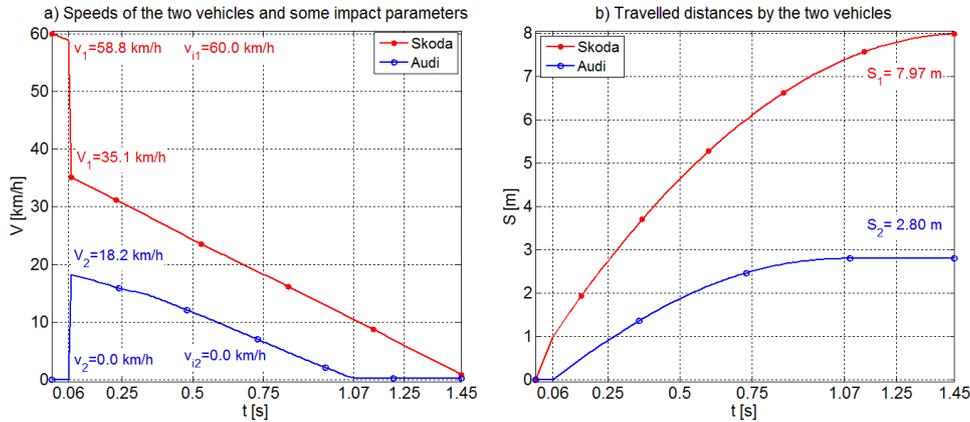


Fig. 3. Speeds of the two vehicles, travelled distances and some impact parameters

As it is noticed from fig. 3a, it can be observed that the speed of Skoda was approximately 60 km/h (driver intended to overtake), and the Audi's velocity was null (driver stops the car).

Fig. 4 shows the angles of rotation around the coordinate axes, from which it follows that the rolling and pitch movements are insignificant. Instead, the yaw movement is pronounced on the Audi, which rotates 97.9 degrees around the vertical axis, and Skoda only 16.6 degrees.

Fig. 5 shows the angular rotation speeds around the coordinate axes.

Roll, pitch and yaw angles of the two vehicles, Skoda and Audi

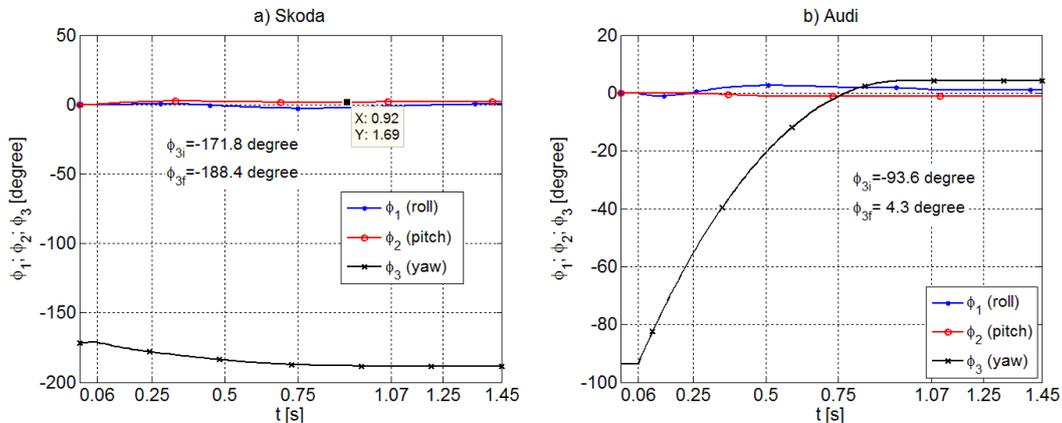


Fig. 4. Roll, pitch and yaw angles of the two vehicles, Skoda and Audi

Roll, pitch and yaw angular speeds of the two vehicles, Skoda and Audi

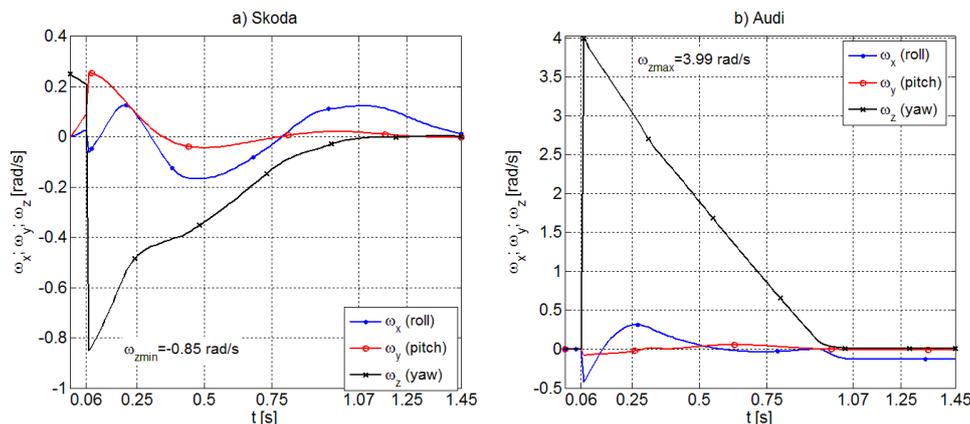


Fig. 5. Angular rotation speeds around the coordinate axes

Because from fig. 5a can be noticed that yaw angular speed  $\omega_z$  is negative after impact, results that Skoda rotates clockwise, as can be seen from the scene of the accident. In addition, because until the moment of impact the angle of rotation is positive, it results that the driver of the Skoda has handled the steering wheel to the left, which confirms the tendency of overtaking and crossing the counter.

Also, from fig. 5b can be noticed that the angular speed  $\omega_z$  is positive during rotation (the rest being null), it follows that the Audi rotates in an anti-gauge (trigonometric) way, as is also seen from the scene of the accident.

Fig. 6 shows the values of the kinetic energies of the two cars and some impact parameters. From graphic can be observed that in initial moment of kinetic energy of the Skoda was  $E_{ci1}=168.11$ kJ, which has fallen to the moment of impact (la  $t=0.06$  s) to 161.41 kJ; kinetic energy of Audi was null ( $E_{ci2}=0$  kJ), this being stopped in the sidewalk.

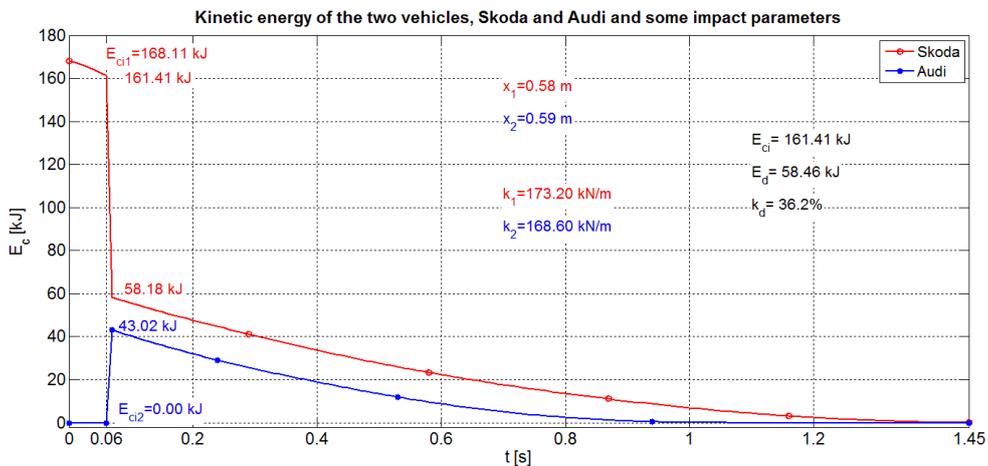


Fig. 6. Kinetic energy of the two vehicles

Because of collision, kinetic energy of Skoda decreased to 58.18 kJ, and of Audi increased to 43.02 kJ. Fig. 6 also shows that the deformation energy of the two cars is  $E_d=58.46$  kJ, and kinetic energy from de beginning of the impact is  $E_{ci}=161.41$  kJ. Results the deformation coefficient [2; 3]:

$$k_d = \frac{E_d}{E_{ci}} \cdot 100 = 36.2\% \tag{4}$$

which shows that from initial kinetic energy 36.2% from it is retrieved in deformations of the vehicles.

Fig. 6 presents the maximum values of deformations too of the two vehicles ( $x_1=0.58$  m for Skoda and  $x_2=0.59$  m for Audi), as part rigidity of them ( $k_1=173.2$  kN/m for Skoda and  $k_2=168.6$  kN/m for Audi).

### III. CRASH AVOIDANCE STUDY

This study is an important issue and will be presented below.

In this case there are the following facts:

- Skoda which overtakes the parked vehicles, circulate irregularly, with 60 km/h speed, bigger than legal one 50 km/h;
- Audi, parked on the sidewalk because the driver wanted to enter into the garden, it was in a position which should create a danger because a part of the vehicle was on the road.

To avoid the accident, Skoda’s driver could be able to reduce the speed of the vehicle and could use the brake from the distance of 15 m, as it can be observed from fig. 7 obtained from PC-Crash software based on avoidance study. It is noticed from Fig. 7 that the accident could be avoided if the Skoda’s speed would be  $V_a = 29$  km /h (details A and B) and the driver would be braked, case in with the car would stop before to hit the Audi.

In fig. 8a are presented the brake forces from the Skoda’s speeds in case of avoidance of the accident, from the graph resulting the delay of 1.2 s too (response time and braking times shown below). In figure 8b are presented speeds

of the two vehicles, as travelled distance by Skoda too, from where results that it stopped before 14.8 m, meaning 0.2 m from Audi, thus avoiding the impact.

This possibility of accident avoidance can also be verified by calculations, using the relation from the literature [2; 3; 6] for the stopping space in this case  $S_o=15$  m:

$$S_o = (t_1 + t_2 + 0.5t_3) \frac{V_a}{3.6} + \frac{V_a^2}{254\phi} \tag{5}$$

The relationship (5) was noted:

.  $t_1=0.8$  s – reaction time of the driver;

.  $t_2=0.35$  s – time from the moment of drive of brake pedal to the beginning of braking process, which in specialty literature is recommended to be  $t_2=0.2-0.5$  s;

.  $t_3=0.1$  s – time in which brake force reached to its maximum value, which in specialty literature is recommended to be  $t_3=0.1$  s for the brakes with hydraulic command;

.  $\phi=0.65$  – adherence coefficient on dray asphalt, which in specialty literature is recommended between  $\phi=0.6-0.7$ .

It is noted that the total delay time is:

$$T = t_1 + t_2 + 0.5t_3 = 1.2 \text{ s} \tag{6}$$

which is found in fig. 8.

To determine the speed of the vehicle with which the accident should be avoided, formula (5) is used, in which  $S_o=15$ , previously established.

Thus, results the quadric equation:

$$0.0061V_a^2 + 0.3333V_a - 15 = 0 \tag{7}$$

which have positive results:  $V_a=29.3$  km/h, which confirms the previous value obtained through the avoidance study using the PC-Crash software (fig.7).

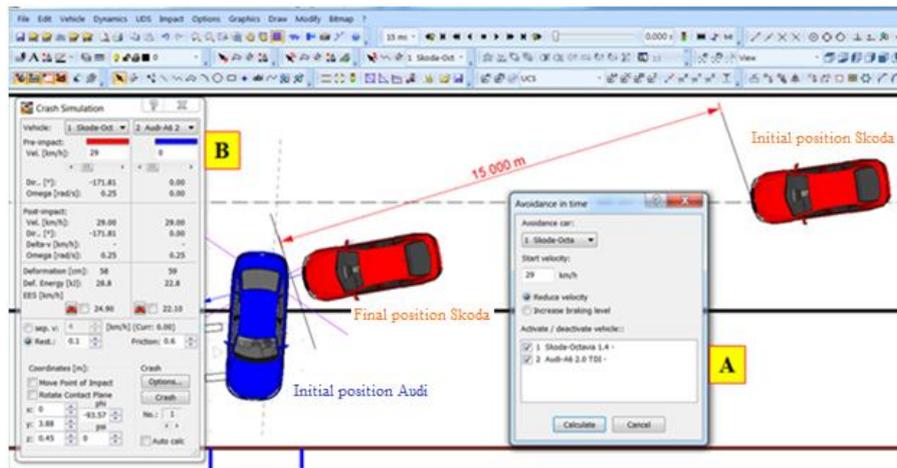


Fig. 7. Avoidance study using PC-Crash software

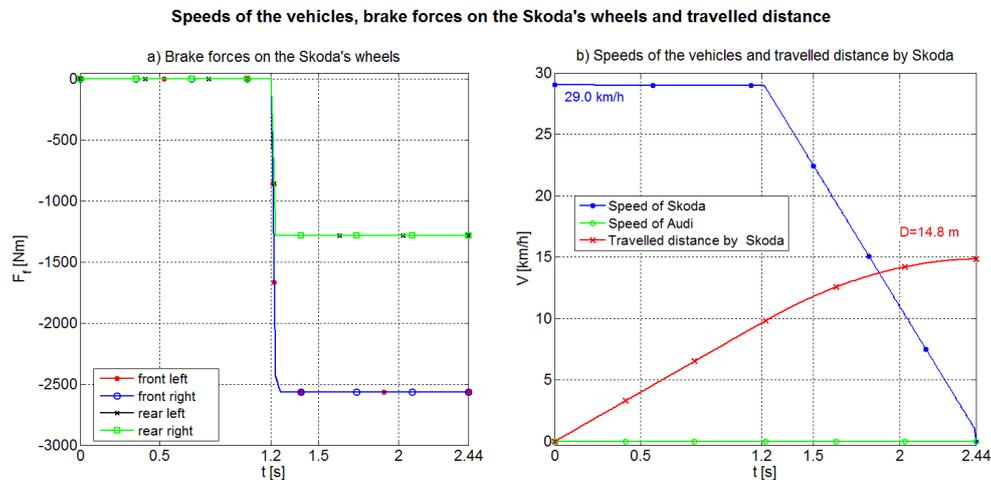


Fig. 8. Speeds of the vehicles, brake forces on the Skoda's wheels and travelled distances

Therefore Skoda's driver could have avoided the accident if he had driven with maximum speed of 29 km/h and he had used the brakes with 15 m before the stopped position of the Audi, a possible distance that ensures good visibility.

If the Skoda had driven with legal speed of 50 m/h, then the driver could have applied the brakes at a distance from Audi of:

$$S_o = (t_1 + t_2 + 0.5t_3) \frac{50}{3.6} + \frac{50^2}{254\varphi} = 31.8 \text{ m} \quad (8)$$

So, the driver of the Skoda had avoided the accident if he would have circulated with a speed of 50 km/h and he would have used the brakes with 32 m before the stopped position of Audi.

#### IV. RECONSTRUCTION OF ROAD ACCIDENTS IN THE PRESENCE OF UNCERTAINTIES

The uncertainties associated with the runway (by coefficient of adherence) and with the driver (through the perception-response time) are now considered and pursuing establishment the stopping distance if the driver had be driven with a legal speed of 50 km/h.

In this case there are considered the limits from specialty literature:  $\varphi=[0.6; 0.7]$ ,  $t_1=[0.5; 1.0]$  s,  $t_2=[0.2; 0.5]$  s,  $t_3=[0.1; 0.1]$  s. Consequently, from formula (5) it is obtained:

$$S_o = [24.5; 37.9] \text{ m} \quad (9)$$

Therefore, in uncertainty condition, the driver of Skoda should have avoided the accident if he would have been driving with a speed of 50 km/h and he had used the brakes with 38 m before the stopped position of the Audi, comparatively to the distance of 32 m from relation (8), if the uncertainties were not considered.

Fig. 9 shows the speeds of the two cars and the distances traveled under conditions of uncertainty on the runway.

Thus, in fig. 9 a coefficient of adherence  $\varphi = 0.6$  was considered, lower than in fig. 3 where it was adopted  $\varphi = 0.7$ .

Comparing the graphs from fig. 3 with those from fig. 9 it is found that in the case of a lower coefficient of adherence, the time of the accident increased (from 1.45 s to 1.67 s) and the distance traveled of the two cars (from 7.97 m to 9.03 m for Skoda and from 2.8 m to 3.94 m for Audi).

In addition, from the two graphs, it is noted that in the case of a smaller coefficient of adhesion (fig. 9) there is an impact in addition to that from  $t=0.06$  s, exactly at time  $t = 0.65$  s.

As can be seen from above, considering uncertainties requires operating with value intervals and not with unique values as do frequently; this aspect involves analysis of the intervals, another methodology for reconstructing the road accidents.

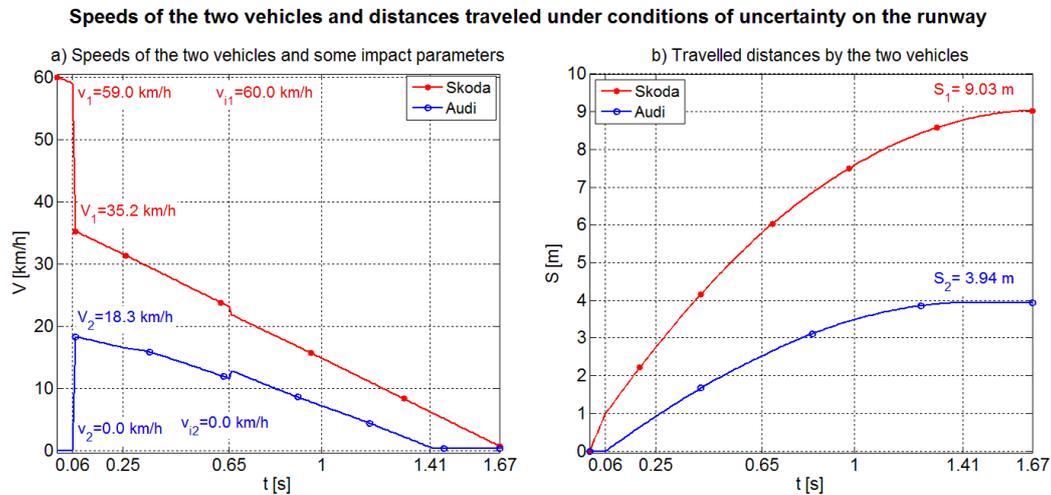


Fig. 9. Speeds of the two vehicles and distances travelled under conditions of uncertainty

## V. CONCLUSION

For establishing vehicle dynamics in case of those involved in road crashes, it is necessary to use the impact models and specialized software, such as PC-Crash software.

For the reconstruction of road accidents, uncertainties of different nature must be taken into account; for parametric uncertainties (related to the mathematical model) it is necessary to use interval analysis and for the subjective uncertainties (related to the technical expert) to uncertainty theory, a branch of complementary mathematics of probability theory.

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