Simulation Model of Risk for Participants in the Movement through Level Crossing

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Key Words: *Individual risk; hazard; exploitation; ensure systems.*

Abstract. *A block diagram has been developed based on a simulation model for the assessment of individual risk, taking into account the influence of the insuring systems of the level crossing. A detailed description of the model's segments is made: rail, road vehicles and pedestrians, automatic crossing devices of level crossing, dangers, realized hazards (incidents), consequences of incidents. In order to describe it we take into consideration the existing connections before level crossing area traffic lights with a barrier and adopted the level crossing hazards, which allow the possibility for improper passing (circumvent of the half-barrier) the level crossing by the road vehicles and pedestrians. The simulation model has allowed to study the dependencies of the influencing parameters on individual risk.*

1. Introduction

The purpose of this work provides a block diagram of a simulation model which assesses the individual risk, taking into account the influence of the insuring systems of level crossing. There is a detailed description of the segments in the model: trains, road vehicles, pedestrians, automatic crossing device, danger, realized danger (incidents), consequences of incidents. The ultimate goal is to determine the dependencies of the influencing parameters on individual risk and to evaluate automatic crossing device of level crossing in terms of safety. In addition we would like to provide and analyze measures to reduce risk. The model is applicable at every stage of the life cycle of the device.

Influencing factors on individual risk are the probability for dangerous failures (that occurs through safety parameters of railway automatics), the parameters of the transport process (intensity of flows of the trains, of the road vehicles and of the pedestrians) and the intensity of dangerous human errors.

Including in the model of possible delays of trains (as in the real case) is not provided because it is a separate very complex task. The studying of the influence of the train category or its speed is a subject of a future research.

Contributions of the paper are the obtained dependencies of defined group output parameters from defined groups of input parameters and the possible identified influencing to individual risk parameters and specifying the extent of their influence in the changing conditions of a particular level crossing.

2. Model Structure

The functioning of the model, in relation to events that could cause the realization of the dangers, is based on the premise that an event cannot typically be dangerous alone; there is a need of a combination of several events.

Danger may arise as a result of simultaneous occurrence of three random events:

- Presence of a train on a level crossing.
- Presence of a road vehicle on a level crossing.
- Automatic crossing devices have no protective function in case of dangerous failure or a dangerous combination from safety failure and human error.

The functioning of the model is illustrated by a simplified functional diagram – *figure 1*.

In the level crossing a train, road vehicles and pedestrians enter (the law of entering is random). When the barrier is launched down, then it is a possibility of a circumvention of road vehicles and pedestrians. At any time point, defined independent hazards randomly arise – *table 1*.

Table 1. Adopted hazards associated with level crossing device

№	Hazards:
	1. On the side the barrier mechanism
O_{11}	Dangerous failures causing premature normalization of automatic crossing devices
O_{12}	Dangerous failures causing do not lowering of the barrier
O_{13}	Dangerous failure - wrong manipulation of distant opening - premature lifting or normalizing
	2. On the part of light signaling for the driver
O_{21}	Dangerous failure of light signaling for the driver
O_{22}	Safety failure of light signaling for the driver
O_{23}	Wrong manipulation at safety failure of light signaling for the driver (wrong manipulation of the driver, when pass along a level crossing area traffic lights)

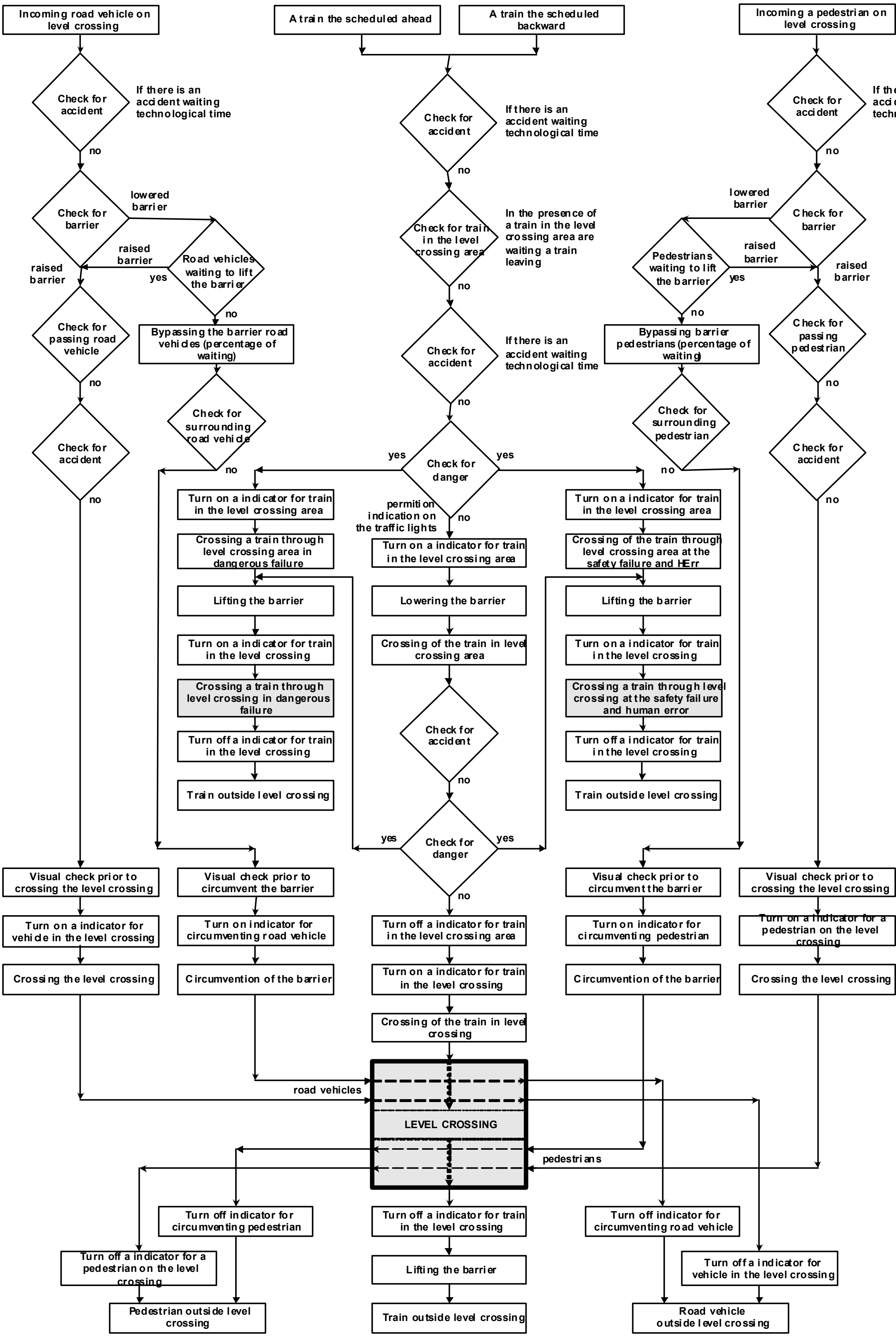

Figure 1. Functional diagram of the simulation model

Table 2. Realized hazards (accidents) on a level crossing

	Reasons for the realization of the hazards -both presence of train and:				Realized hazards:
	hazards	**circumvention**	**vehicle**	**pedestrian**	
PO_1	–	yes	yes	–	collision of a train with circumambulate vehicle
PO_2	group 1[1]	–	yes	–	collision of a train with vehicle at dangerous failure
PO_3	group 2[2]	–	yes	–	collision of a train with vehicle at safety failure and human error
PO_4	–	yes	–	yes	collision of a train with circumambulate pedestrian
PO_5	group 1	–	–	yes	collision of a train with pedestrian at dangerous failure
PO_6	group 2	–	–	yes	collision of a train with pedestrian at safety failure and human error

[1] Group 1 is a hazards: O11, O12, O13 and O21 (*table 1*).
[2] Group 2 is a hazards: O22 and O23 (*table 1*).

The model provides hazards leading to incidents – *table 2*. These events will be examined successively based on the algorithm for passing the level crossing.

The movement of trains, road vehicles and pedestrians in the level crossing (with continuous checking for the occurrence of incidents during the movement) model is realized by a separate segment in the program [1,2,3,4,5,6].

We will consider first the movement from the perspective of the driver of the train, and then from the perspective of drivers of road vehicles and pedestrians. They see different signals that are synchronized (raised or launched down barrier and different signaling).

Firstly trains enter the area preceding level crossings. During the simulation, in conjunction with the movement of trains through the area preceding level crossings and level crossing, the program performs logical checks. The program performs a logical check for the presence of an incident occurring at the time of entering the area preceding level crossings by the next train (done only for modeling purposes).

If we have a registered incident in the level crossing (envisaged indicator for incident is included), then the train cannot enter the level crossings area (the program puts it on hold).

It is assumed that the trains move successively, i.e. a train can enter the preceding level crossings area only when a previous one has left the level crossing and if indicator for an incident is not activated (no incident on the level crossing). Then the programme performs the following checks –for possible existence of previous train (check another indicator designed specifically for this).

In the previous section, before level crossings, there is a signaling (traffic lights) to the train driver. The testimony of the traffic lights can be lit and unlit (white flashing light – indication „closed level crossing").

Normally the level crossing is „open" (the barrier is raised). Then before the level crossing a signal is unlit (dark). At entry of a train in a level crossing area, an automatic crossing device is triggered and the level crossing is „closed" (barrier is lowered and the signaling traffic lights before level crossing area are with white flashing light). The train passes through the level crossing area with the maximum speed. In this case, a normal (not dangerous failure occurred), an incident is possible only as a result of circumvent of the barrier from a road vehicle or a pedestrian.

If the train has already entered the level crossing area the level crossing is not „closed", the level crossing traffic lights remain unlit, that obliges the train driver to pass with caution and speed that will allow him to stop in case of a road vehicle in the level crossing. Transit time is greater in this case.

In this case any safety failure, which can lead to an incident only in combination with human error (train driver error – for example, reduced alertness, distraction, fatigue, faulty judgment, the driver does not react properly to signals, etc.). If safety failure and human error do not occur simultaneously, an incident does not occur.

Indication of the traffic lights „closed level crossing" may be based on occurred hazard (O11, O12, O13 and O21), representing a dangerous failure – then the train will continue at high speed, and the barrier will not be lowered.

The characteristic points of entry and exit, before level crossing area and the level crossing, by the train (respectively lowering and raising the barrier), are activated and deactivated by relevant indicators. Based on the status of these indicators (and other relevant indicators in different situations: the movement of road vehicles and pedestrians, for danger, for occurring incidents), the occurrence of the incident are continually checking by the veracity of logical conditions.

The incoming to the level crossing by road vehicles depends on the position of the barrier – raised or lowered.

When the barrier is lifted, the road vehicles may cross the level crossing (which activate relevant indicators) and leave the model. There is a possibility for crossing the level crossing of the road vehicles only sequentially (one after another) and not parallel. Before crossing a visual check is envisaged of the driver for the presence of an approaching the level crossing train.

When the barrier is lowered, a part of the waiting road vehicles (with certain probability) will pass improperly (circumventing the barrier).

Incoming to the level crossing pedestrians also react depending on the position of the barrier –raised or lowered. They also provide time for visual control for a coming train. When the barrier is lifted, the pedestrians cross the level crossing and leave the model, and when the barrier is lowered, some of them (also with a certain probability) circumvent the barrier and also leave the model. For pedestrians indicators showing their crossing are also provided.

For road vehicles and pedestrians both adequate time for visual inspection and time for crossing (or circumventing) are provided during which the indicators are activated.

Checks for an incident are carried out continuously depending on the state of the indicators for train, road vehicles and pedestrians and hazards which are grouped in combinations (formulas in the program) for different types of incidents. When an incident occurred the program transfers control to a segment in the model to calculate the results and handling the statistics (summarizing and averaging the results), then the simulation process continues. The results of the model are obtained on a yearly averaged basis.

3. Study of Individual Risk

Using the proposed simulation model, an analysis was made of the individual risk for the road users in level crossing equipped with automatic crossing device.

Influences of the hazards are examined, taking into account their intensity variation within a certain range, and for the research of dependencies we have selected five points of the range. Below the values at just middle and end points are featured (intermediate points are median values) – these values in the model are defined in terms of time parameters, i.e. mean time of occurrence of hazards.

For the hazards: dangerous failures causing „premature normalization of automatic crossing device", „dangerous failures causing not falling of the barrier" and „dangerous failure of the light signaling the machinist" is in the range 10^{-8}–10^{-6}. A dangerous failure – „wrong manipulation of distant open" is in the range 10^{-6}–10^{-4}. „ The Safety failure of light signaling the machinist" is in the range 10^{-4}–10^{-3}, and „the hazard of wrong manipulation of the machinist" for safety failures passing over a level crossing signal is in the range 10^{-3}–10^{-2}. The last two hazards lead to an incident only in combination, and the advent of the combination is also a rare event.

A crossing through level crossing is action which carries a risk – one side for passing pedestrians and the other for traveling in the transition road vehicles. The risk is different for pedestrians and passengers.

Figure 2 presents the results of the study of individual risk for travelers in road vehicles and pedestrians circumventing the barrier. Safety parameters of insured systems do not influence the individual risk. Road vehicles and pedestrians, circumventing the barrier, pose a danger of an incident nature, thus changing dangers of ensures systems do not affect the values of individual risk, which is the expected result. The nature of the dependencies is determined solely by the random processes of circumvention. The character would be preserved even when other values of the random number are used for the circumvention. Dependence would lend a distinctive character depending only on influencing parameter, regardless of the scale of representation.

Increasing individual risk for passengers in road vehicles leads to increase in the intensity of dangerous failures (*figure 3*) and the intensity of the combination of safety failures and human errors (*figure 4*).

Logically dangerous failures and combination of safety failures and human errors affect differently (causing various incidents and different individual risk) for the set point of the input data. The number of incidents from dangerous failures is greater than the number of incidents caused by a combination of safety failures and human errors.

A comparison between *figure 5* and *figure 6* shows very low relative influence of the intensity of safety failures and human errors on average individual risk.

Figure 2, *figure 5* and *figure 6* show the relative influence of the barrier circumvention road vehicles and pedestrians, and the curve retains its character.

On the resulting individual risk pedestrians have a greater relative influence than road vehicles (as specified in the initial values) – *figure 6*. This is related to the fact, that the incidents at the level crossing are mainly related to violations of passing and much more rarely – to failures in the level crossing automation

The resulting characteristics are an expected result. There is a deviation from the course of the curves obtained, because of some zero values of the individual risk for road vehicles (*figure 4*). There is also an increase of steepness of the curves at higher values of the dangers.

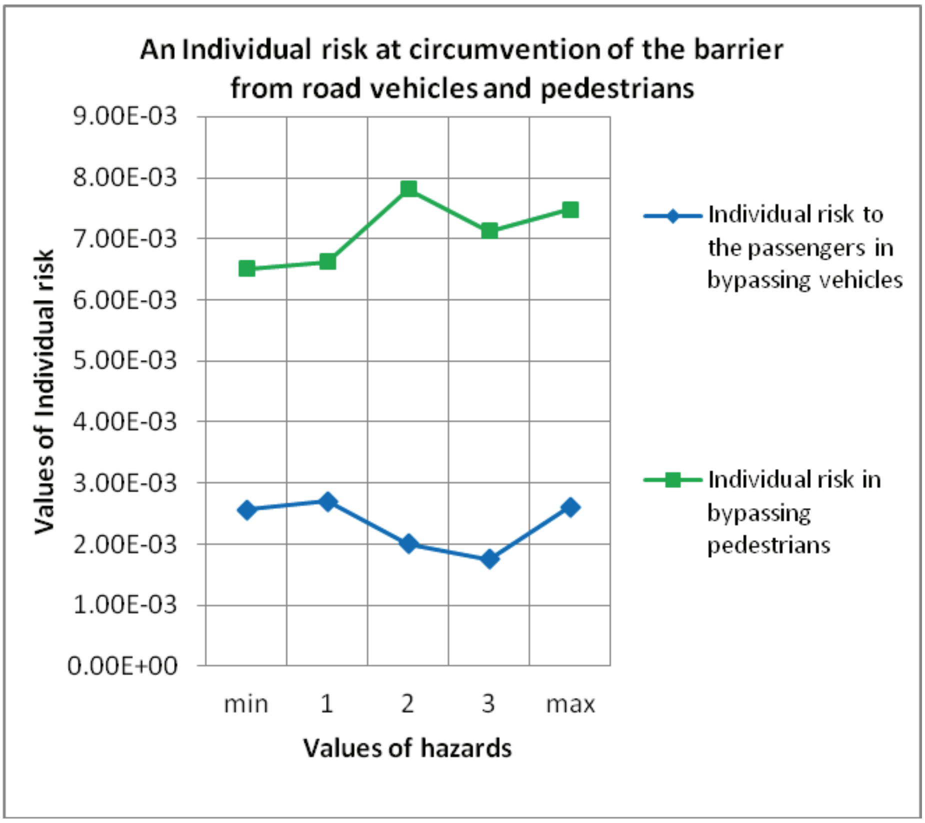

Figure 2. An Individual risk at circumvention of the barrier by road vehicles and pedestrians

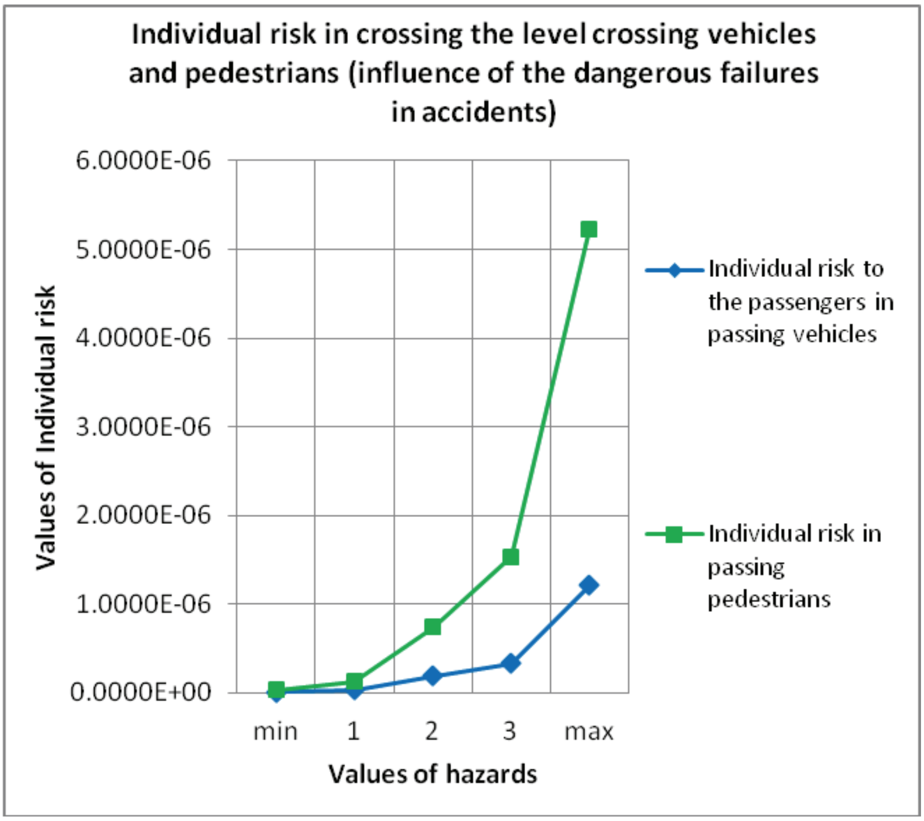

Figure 3. Individual risk in crossing the level by crossing vehicles and pedestrians (influence of the dangerous failures in accidents)

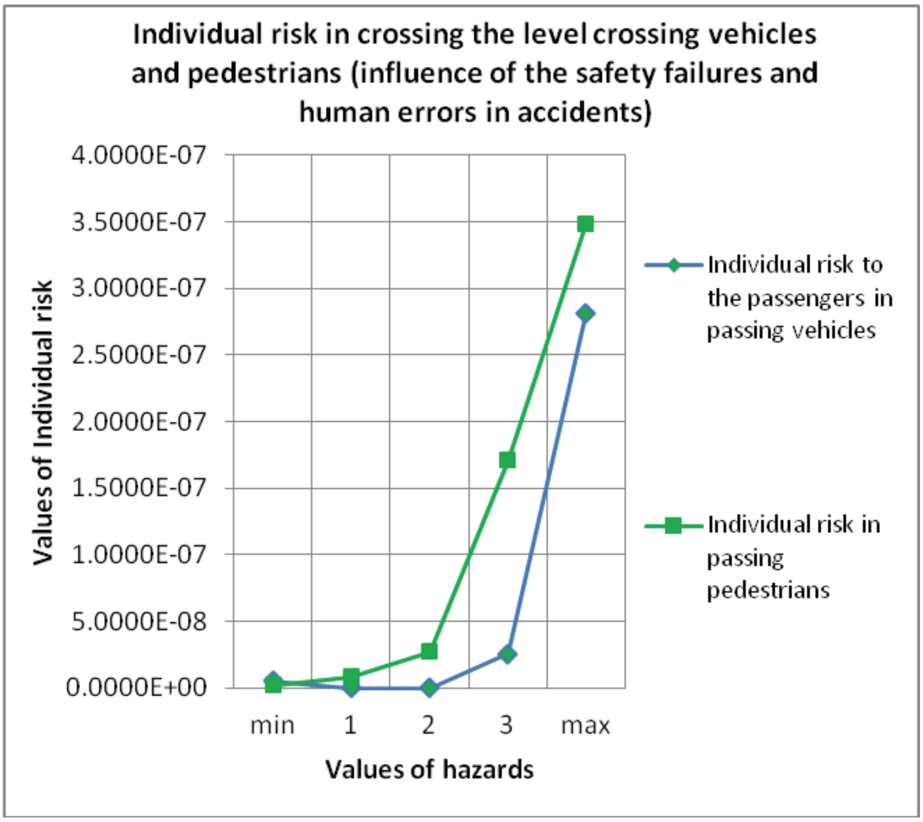

Figure 4. Individual risk in crossing the level crossing vehicles and pedestrians (influence of the safety failures and human errors in accidents)

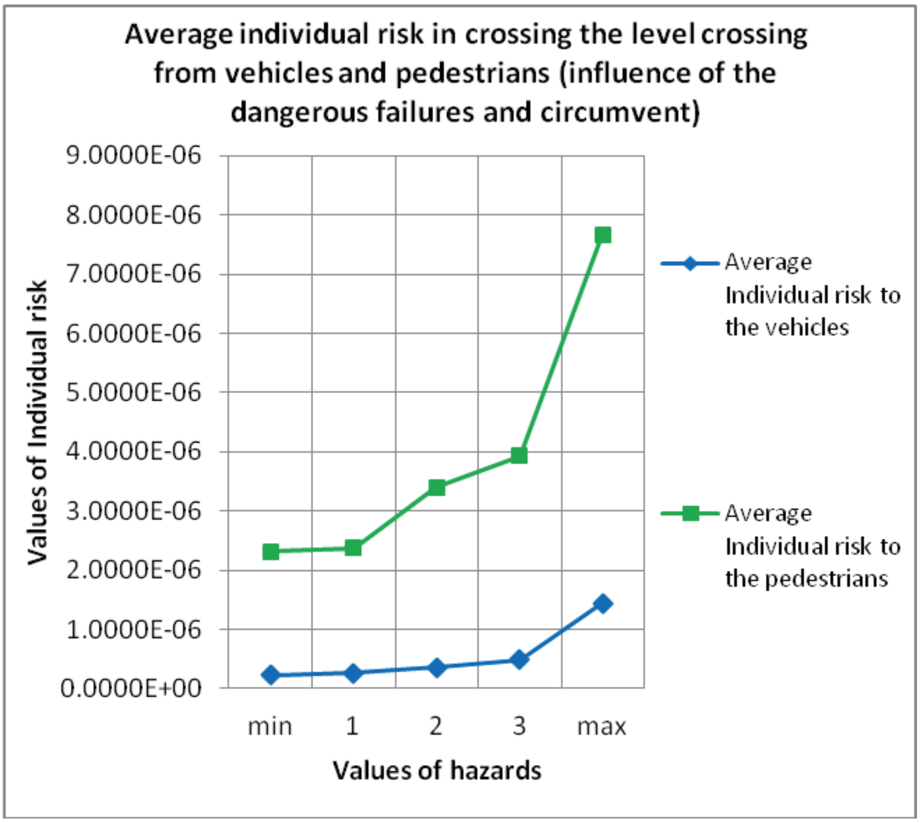

Figure 5. Average individual risk in crossing the level crossing from vehicles and pedestrians (influence of the dangerous failures and circumvent)

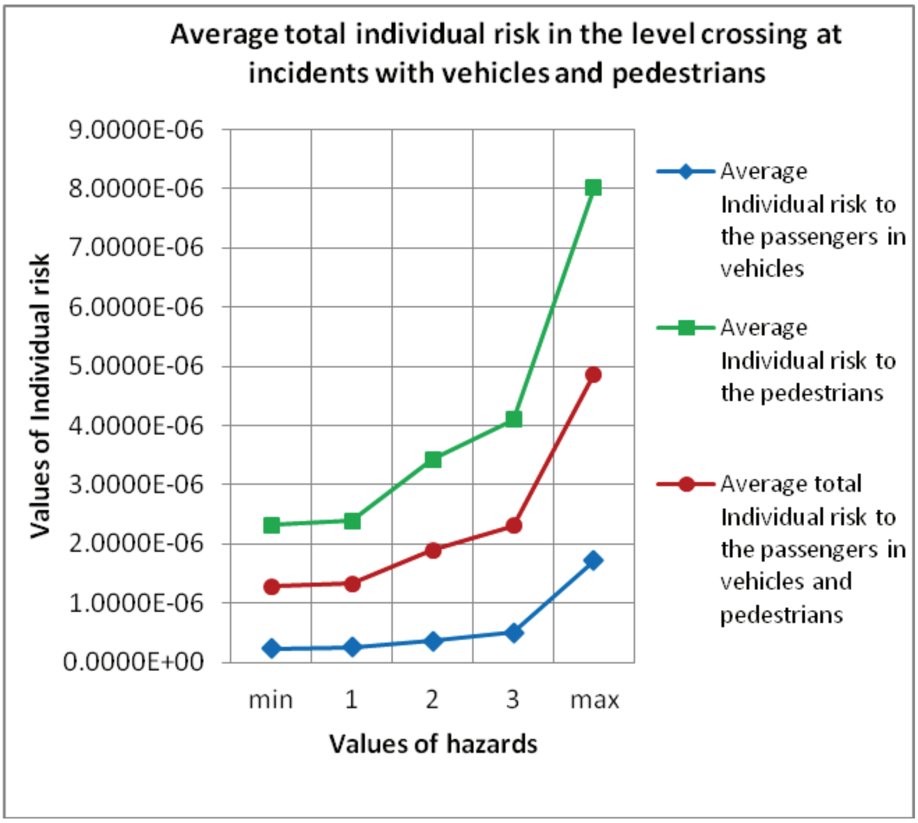

Figure 6. Average total individual risk in the level crossing at incidents with vehicles and pedestrians

4. Verification of the Model

Verification of the simulation model was carried out.

1. First, verification is made, the program does not run on automatic execution, but manually, through which it is performed step by step for proper execution of each operator and parameter values. Thus all branches of the projected algorithm were crawled. By tracking each step is checked:

– Train traffic: traffic on the timetable, entering the level crossing area by a train, entering and leaving the level crossing by the train.

– The movement of road vehicles and pedestrians: entering and leaving the level crossing byroad vehicles and pedestrians, the possible circumvention of the barrier by road vehicles and pedestrians during the waiting.

– The occurrence of hazards (and the combination of hazards) in accordance with the specified probability and a set duration of actions.

– The management (lowering) of the barrier depends on the presence of a train in the level crossing area and leaving by the train of the level crossing (lifting of the barrier).

– Failure in the management of the barrier in occurred danger (wrong lifting barrier).

– Presence of an incident (realized hazard) and why it occurred.

– Proper registration of the incidents and processing the received statistics for each incident.

– Correct performance of the conditions for the logical end of the simulation – the occurrence of any hazard and availability of recorded incident of any type.

– Correct sequence of occurrence of various events in the model during the simulation.

2. Simulation of real cases with predetermined outcomes (extreme cases of parameter values) and evaluation of results based on simulation.

– When removing the ability to circumvent the barrier (option with whole barrier), incidents obtained in the model are only by the occurrence of failures in the insuring system.

– The exclusion of pedestrian traffic leads to incidents occurring only with road vehicles.

– Shutdown the movement of road vehicles, incidents occur only with pedestrians.

– Shutdown the movement of road vehicles and pedestrians, there is no incidents.

– Assuming the device is extremely reliable (by excluding the occurrence of failures in the insuring system) then we have registered only incidents of circumventing.

3. Estimation of the distribution of the absolute time of registration of incidents.

5. Conclusion

A simulation model is proposed for the study of individual risk for road users in level crossing equipped with automatic crossing device. Experimental results are obtained on an annual basis, the dependence of the intensity of the individual risk of dangerous failures, the intensity of safety failures and human errors, and the intensity of the circumvention the barrier of level crossing road vehicles and pedestrians.

The obtained experimental dependencies allow obtaining results for:

– Practical risk assessment of a particular level crossing where individual risk must be within certain limits.

– An individual risk assessment of the existing systems in order to compare changes in parameters (for improvements, implementations), and to demonstrate that the risk posed by them is equal to or less than the previous.

Through the resulting dependencies of defined group output parameters from defined groups of input parameters, influencing to individual risk parameters can be identified and the extent of their influence in the changing conditions of a particular level crossing can be specified.

The used approach and the computer programs can be applied to develop various simulation models and study of the individual risk for people exposed to the impact of the respective systems

6. References

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