Natural hazard induced risk: a dynamic individualised approach for calculating hit probability on networks

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ABSTRACT

In the context of natural hazard and risk assessment in Switzerland, it is common to identify the collective and individual fatality risk (Bründl 2009). However, this approach is a static perspective. Consequently, the deduced results for the individual mortality risks on transport networks (street, railway), only describe the additive independent risk for any person on the endangered network section. Being aware of this limitation, it is the aim of this study to calculate the total hit probability for a specific single person, who is driving on a network section from A to B. Therefore, the calculation of individual risk is adapted and integrated in a model, whereby dynamic calculations for different scenarios are possible. The results shows that despite the changing of input parameters (speed, simulation time frame, …) the differences between the static and the dynamic approach mainly varies related to the hit probability.

KEYWORDS

natural hazards; risk analysis; hit probability; network analysis; GIS

INTRODUCTION

In the context of natural hazard and risk assessment in Switzerland, it is common to identify the collective and individual fatality risk (Bründl 2009). This approach, however, is a static perspective of the exposure to natural hazards (Bründl et al. 2010, Fuchs et al. 2013). The results of this approach, particularly for the fatality risks on transport networks (street, railway), only describe the additive independent risk for any person in general on the endangered network section. Being aware of this limitation, it is the aim of this study to quantify the consequences of a change in perspective from a static to a dynamic individualised perspective. Consequently, the objective is to calculate the total hit probability for a specific person who is driving on a network section from A to B (Fig. 1).

The following main aspects are used as a framework for the study: The first step, starting from the static approach, is the analysis of how the calculations of hit probability have to be adapted to simulate the dynamic individualised perspective, and the subsequent implementation of this adapted modelling approach. Accordingly, the second focus lies on the assumed difference between the two approaches (static vs. dynamic individualised) by comparing the results providing the same baseline. In addition, the influence of the driving direction to the

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results of modelling the hit probability for the dynamic individualised perspective will be clarified. Finally, the system dynamic and sensitivity of the results according to the variability of the input parameters is tested. In this paper, only a selection of the overall results is presented.

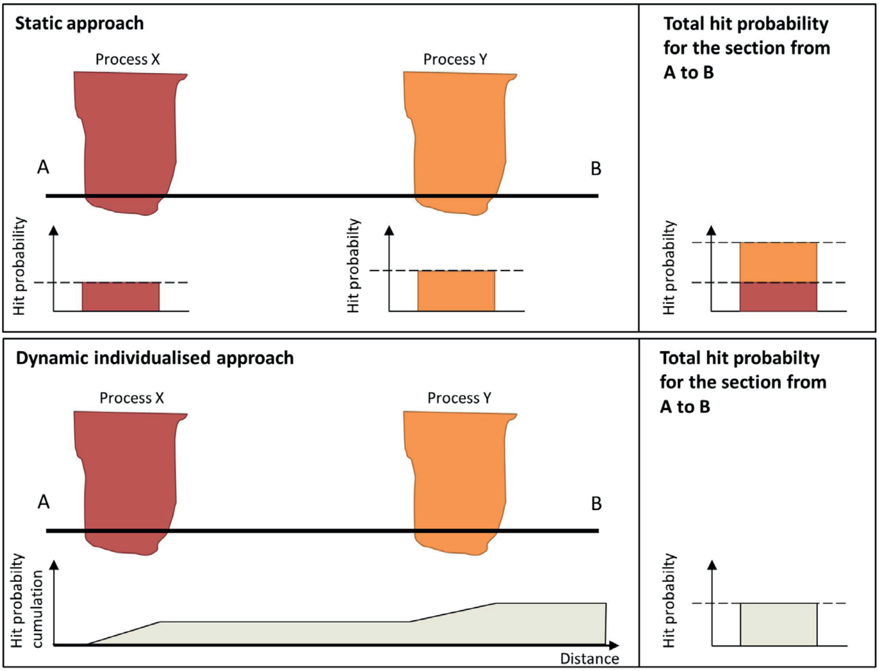

Fig. 1: Scheme of the static and dynamical individualised approach.

METHODS

In a first step, the mathematical formulas will be adapted with the concept of conditional probability. Secondly, a network data model system will be constructed for the modelling of the different aspects as outlined above. Finally, the planned analysis of sensitivity will be realised by variation of the different input parameters.

1) Adaption of hit probability calculation

The common calculation of hit probability related to natural hazards for individuals is a function of the following input parameters: the spatial appearance probability of the process ***($p(sa)_j$)*** , the probability of an event ***(p_j)***, the length of the endangered section ***(g_j)***, the speed of the individual ***(v_i)***, and the probability of rear-end collision accident ***$p(reca)$***. Furthermore, in the case of a risk analysis on a network, two scenarios are defined, namely the direct hit ***(DH)*** and the ride-into-accident ***(RA)*** (Bründl 2009). Because the focus is on the aspects of the individual driver on the network, the influence of other decision-makers, who are causing closures or early-warning etc., will be ignored. Based on this aspect, the two probabilities are calculated per endangered section g_j and per year (Formula 1).

$$p(DH) = p_j \times p(sa)_j \times \frac{g_j}{v_i \times 24000} \qquad and \qquad p(RA) = p_j \times p(reca) \quad p(X) \in [0,1]$$

Formula 1: Calculation of the probability of direct hit and ride-into-accident out of Bründl (2009).

All these parameters are also integrated into the adapted calculation for the dynamic individualised approach. In order to take the dynamic aspect better into consideration within the constructed calculation model, the probability of the ride-into-accident ***(RA)*** is completed with two elements. First, the spatial appearance probability of the process ***($p(sa)_j$)*** is integrated into the formula. Second, the probability of rear-end collision accident ***p(reca)*** is calculated depending on the speed of the individual ***(vi)*** deduced from the physical relation between the distance of braking deceleration and the speed, and by following the recommended values in ASTRA (2012) (Fig. 2). The blue function represents the physical connection of the braking distance and the speed of a car with a braking deceleration of 8 m/s².

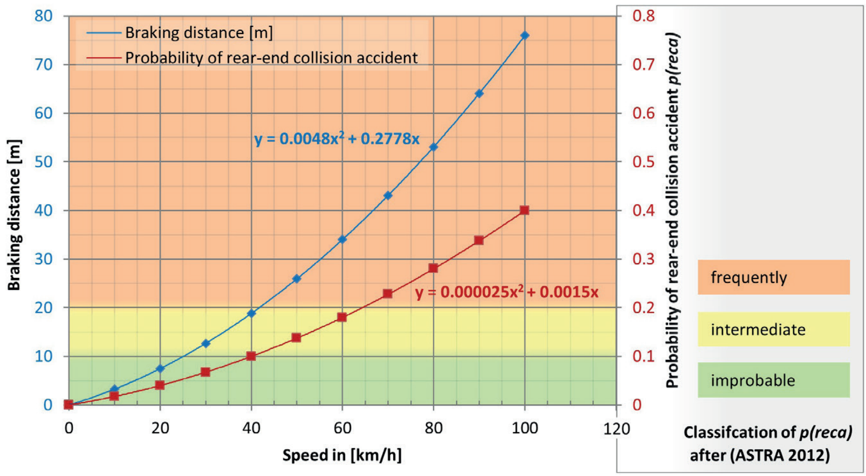

Fig. 2: Derivation of the connection between the speed of the individual ***(v_i)*** and the probability of rear-end collision accident ***p(reca)***.

In addition, the assumption was taken; that a probability in the class "intermediate" of the classification after ASTRA (2012) nearly corresponds to a speed between 40 km/h and 60 km/h. Based on these considerations, the relation between speed and the probability of rear-end collision accident is deduced.

Subsequently, based on these formulas for the dynamic calculation, a norm probability for each scenario for one meter per hour is formed (Formula 2). The general determination is that for this unit the static and dynamic hit probability is identical.

$$p_n(DH) = \frac{p_j \times p(sa)_j}{v_i \times 24000 \times 365 \times 24} \quad and \quad p_n(RA) = \frac{p_j \times p(sa)_j \times f_{reca}(v_i)}{g_j * 365 * 24} \quad p \in [0,1]$$

Formula 2: The deduced norm probabilities of the two scenarios direct hit and ride-into-accident.

Afterwards the hit probability is calculated for each meter along the simulated path from A to B with the integration of the converse probability (the odds that the individual has travelled the path before without being hit) (Formula 3).

$$P_{A \to B} = 1 - \prod_{j=1}^{m} (1 - P_j)^{l_j} \quad with \quad P_j = 1 - \prod_{z \in X_j} \left(1 - p_n(DH)_z\right) \times \left(1 - p_n(RA)_z\right)$$

Formula 3: The calculation of the hit probability of the dynamic approach.

The reason for integrating the converse probability into the calculation is to consider the aspect that a specific individual moving on the section cannot exceed a hit probability above 1. Thereby the variable $\boldsymbol{X_j}$ represents the amount of the different natural hazard processes ***(z)***, which endangered the specific metre, and the variable $\boldsymbol{l_j}$ is the length of the part in an endangered section with the same combination of natural hazard processes.

2) Network data model system

The main aim of the constructed network data model is the possibility to simulate different scenarios. In this context, the main requirement is that the data model is adaptable to any combinations of the above-mentioned input parameters and usable for any section in reality. The simulation model is built in Python, a programming language for geoprocessing (Python 2015). Basically, the model calculates the hit probability for each metre by passing the path between A and B. Thereby, the smallest distance unit in the simulation model is one metre. First of all, the real section from A to B is imported in the calculation system. During this process a list with the endangered sections and their specific parameters is created. Afterwards, a simulation path as a sorted list of metres from A to B is constructed. Thereby each metre has the information of which processes endangered it. Finally the hit probability of the complete path is simulated through.

The specific baseline for this study is represented by the section between Interlaken and Brienz in Switzerland. This course has a length of 18 kilometres and, overall, is endangered by 75 natural hazard processes. Table 1 shows an overview of the situation of exposure by natural hazards.

Table 1: Overview of the situation of exposure by natural hazards for the simulation baseline between Interlaken and Brienz (CH).

Endangered section	Rockfall	Debris flow	Avalanche	Landslide	**Total**
Count	16	20	20	19	**75**
Average length [m]	358	292	439	337	**357**
Sum of length over all sections [m]	5,731	5,849	8,785	6,411	**26,776**

Thereby the endangered sections have been deduced from the natural hazard information maps of the canton of Berne (AGI 2015). The verification and further description and assessment of these sections are not subject of this study.

3) Analysis of the results and their sensitivity to input parameters

Based on the created simulation model, the results have been compared with the static approach and the influence of the direction of travel has been quantified. Furthermore, the sensitivity of the results dependent on the different parameters has been tested. For this purpose, a simple testing workflow has been defined. In a first series of simulations, some of the parameters that are dependent on the natural hazard have been varied, while, in a second series, the same was done with those parameters that are dependent on the individual. As a result, the dependency and the impact of the input parameters on the results have been evaluated.

RESULTS

For the initial situation S_0 to compare the two approaches and testing the sensitivity of results, the parameters are defined as mentioned in Table 2.

Table 2: Parameters setting of the initial situation S0 (adapted from Bründl (2009)).

	Rockfall	Debris flow	Avalanche	Landslide
Spatial appearance probability of the process $p(sa)_j$	0.01	0.8	0.7	0.1
Probability of an event (p_j)	once per 30 years = 0.0333..			
Speed of the individual (v_i)	60 km/h			

For the spatial appearance probability of the process, the standard values recommended in Bründl (2009) are applied. The probability of an event and the speed of the individual are fixed. Furthermore, the individual is passing the course of Interlaken to Brienz twice a day (once in each direction) and every day per year (one year = 365 days). That means that the simulation is running over a period of one year.

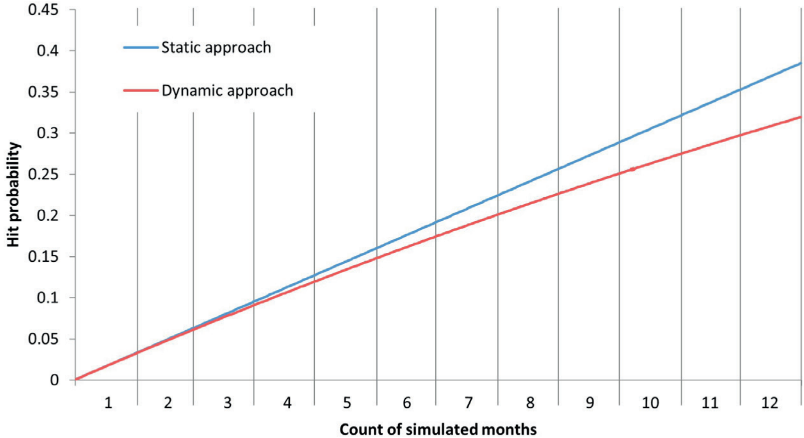

Fig. 3: The growth of hit probability over one year for the static and dynamic perspectives.

1) Comparison of the two approaches

If we compare the results of the two approaches for one year (Fig. 3), it appears that the longer the simulation is running the range of the difference increase.
The hit probability of the static approach shows a continuous growth, which means the rate of increase is constant and could theoretically exceed the value 1. In contrast, applying the dynamic approach, the rate of increase of hit probability decreases and, over time, it approximates the value 1. This behaviour is explained by the increasing converse probability factor, which is fed into the calculation of the dynamic approach and prevents the value from exceeding the value 1. If we compare the hit probabilities for the two approaches for one day and for one year (Table 3), the results indicate that the difference for one day is insignificant. However, by simulating over one year the difference is about 17 percent.

Table 3: Comparison of the results of hit probability for the two approaches for the periods of one day and one year

Probability		Static approach	Dynamic approach	Percentage (static value = 100%)
Day	Direct hit	1.4606E-06	1.4606E-06	99.999927
	Ride-into-accident	1.0530E-03	1.0524E-03	99.94737
	Total of scenario's	1.0544E-03	1.0539E-03	99.94729
Year	Direct hit	5.3313E-04	5.3299E-04	99.973348
	Ride-into-accident	3.8434E-01	3.1910E-01	83.02566
	Total of scenario's	3.8487E-01	3.1946E-01	83.004947

Correspondingly, the value of the norm probability plays an important role: The smaller the value of the norm probability, the smaller the difference will be after one year. This implies that the converse probability factor is growing slower. Furthermore, this connection is also reflected by the two different scenarios “direct hit” and “ride-into-accident”, whose values of hit probability per day differ by a factor of about 720.

2) Influence of the direction of travel

Figure 4 schematically visualise the results of the analysis regarding the influence of the direction of travel. Thereby the parameter V_x represents the incidental costs if something happens (red cross). The coloured boxes stand for two different hazardous sections with a probability that something happens (p_x). In the case, that we have no valuation of the event ($V_x = 1$), only the probabilities are relevant. In this situation the results for driving from A to B or from B to A will be the same. Also in the two special cases if the valuation or the probability that something happens for the different sections are the same, the driving direction has no influence (as mentioned in the calculation in Fig. 4).Yet, if the various hazardous sections are evaluated differently (for example in the calculation of risks), then the different values will emerge for the two directions of travel.

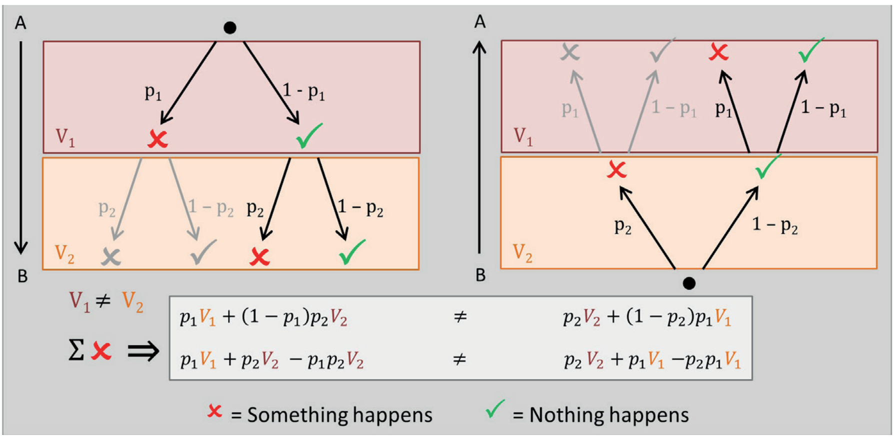

Fig. 4: Scheme of the influence of the driving direction for the results.

3) Sensitivity

Following the results for the two parameters, the probability of an event (p_j) and the speed of the individual (v_i) are presented. The speed is varied between 30 and 100 km/h. Figure 5 A shows the plotted results from a simulation period over one year. The lower the speed, the flatter is the graph of the result. The higher the speed, the more the curvature of the graph increases.

The parameter probability of an event (p_j) is varied with the common values in Switzerland between one event per year and one event per 300 years. Figure 5 B, presents the plotted results about a simulation period over one year. The more probable the event is, the steeper the graph of hit probability is growing before it is flattening by reaching the value 1. The rarer an event is, the flatter the hit probability is growing. Clearly apparent is that the hit probability of one individual cannot exceed the value of 1. In contrast, calculating the static individual hit probability for the different values of p_j, the results may exceed 1.

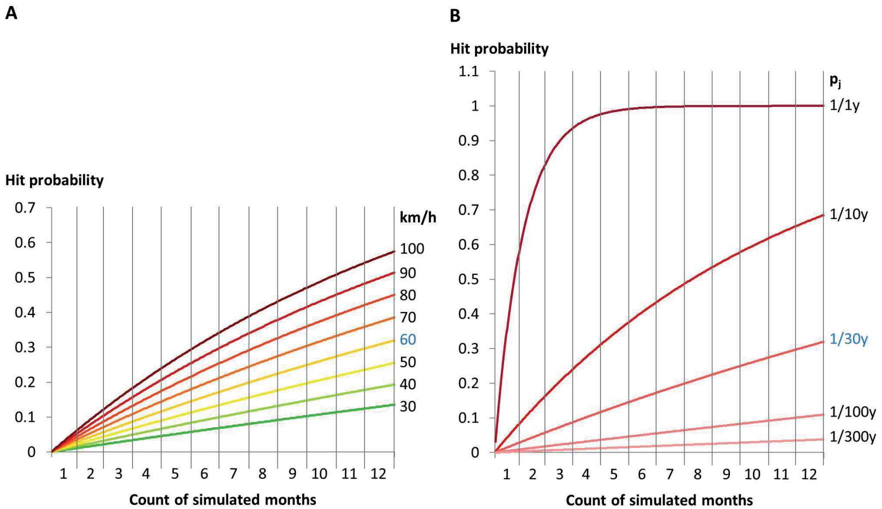

Fig. 5: A: The growth of hit probability over one year for different individual speed values. B: The growth of hit probability over one year for different event probabilities. Blue value: initial situation S_0.

CONCLUSIONS

Generally, the hit probability for an individual with the dynamic approach is limited to the value of 1. A value greater than 1, does not make sense for a probability. This means that the dynamic approach generates more realistic results for an individual person. The benefit of this approach is that it allows making a statement for the hit probability for a single specific commuter and not only for a group of individuals moving on the section.

The larger the norm probability and the longer the simulation period, the differences increase between the static and dynamic approaches. At the level of probabilities, the driving direction has no influence. However in situations, where a valuation of the different probabilities is condacted, different values result for both directions of travel.

This study proposes a change to a more dynamic perspective in risk analysis, starting with the hit probability on networks. The results according to the dynamic individualised perspective will also stimulate a new dimension for the discussion of risk management. Furthermore, the developed method features applications for further routing services and other mobile devices, and could additionally be applied to questions concerning the insurance sector. Finally, the benefit for road operators is the possibility to make more precise statements for single commuter with different usage behaviours on their roads. This paper presents an overview and some results from an ongoing study. More information and details were published in early 2016 (Schönthal, 2016).

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