RISK-ORIENTED VS HAZARD-ORIENTED DECISION-MAKING FOR OPENING AND CLOSING OF TRAFFIC ROUTES

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ABSTRACT: People expect to be safe when driving on roads. During winter, local avalanche services in charge for infrastructure safety continuously assess the hazard situation along traffic routes. Based on meteorological data, national or regional avalanche forecasts and their own interpretation of the specific avalanche situation, they either decide to keep traffic routes open or to close them when an avalanche might hit the road. Even more difficult can be the decision to re-open e.g. a road section. Today, in Switzerland these decisions are hazard-oriented, which means that actions are taken when the hazard is considered too high.

In many alpine countries, decisions on the realization of permanent protection measures such as avalanche defense structures are based on risk assessments. In structured working steps supported by software tools, the risk to people and property without and with planned measures are compared and related to the cost of measures. The resulting cost-benefit-ratio and the level of individual risk are taken as decision-criteria among others such as social acceptance and environmental sustainability.

Therefore, it is obvious that decisions of safety services for infrastructure safety could also base on risk criteria rather than on hazard criteria in future. Based on procedures developed for risk-oriented planning of mitigation measures we present a method for the estimation of individual risk of people along roads. We compare the risk with accepted risk thresholds for individual risk and discuss legal limitations of risk-oriented decision-making of avalanche safety services in Switzerland. We conclude that risk-oriented decisions encounter difficulties when the legal system is not risk-oriented.

Keywords: avalanche hazard and risk assessment, duty of care, individual risk, decision making, safety services

1. INTRODUCTION

Risk-oriented decision making has become a common practice for the evaluation of effectiveness and efficiency of mitigation projects. As an example, the Federal Office for the Environment (FOEN) of Switzerland introduced the software EconoMe (www..econome.admin.ch) as a mandatory tool for a comparable evaluation of the effectiveness and the economic efficiency of mitigation measures against gravitational natural hazards. EconoMe is based on the general risk concept for natural hazards (Bründl et al., 2009; Tobler and Krummenacher, 2013), and is available as Online and Offline-Version. It guides users through a quantitative risk assessment to calculate collective (societal) and individual risks and to compare the calculated individual risks with defined protection goals to check whether they are violated and measures are needed (Dolf et al., 2014). Potential mitigation measures are evaluated by the ratio of calculated annual risk reduction (=benefit) and the annual cost, i.e. the benefit-cost-ratio as criteria for the economic efficiency. Since ten years, EconoMe is in operational use (Bründl et al., 2016).

In Switzerland, in the daily decision making process of avalanche services, risk is not explicitly considered. Decisions on avalanche safety are based on the evaluation of a specific hazard situation. When a road is considered to be endangered, it is closed, regardless whether one or ten persons are at risk. Since the consideration of risk plays a crucial role in planning of permanent mitigation measures, it is the goal of a project supported by the Swiss Innovation Agency Innosuisse to investigate whether the consideration of risk would also be an added value in decision making of avalanche safety services.

The terms danger, hazard and risk are often mixed up. Since they are key terms in this paper, we define them as follows to avoid misinterpretation:

Danger is defined as condition, circumstance or process, which can result in damage and/or injury (SLF, 2018).

Hazard is defined as a specific danger for an object. A hazard is related to the occurrence of an expected dangerous event, which might

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cause harm to a person or an object.

Risk describes the likelihood of occurrence and combines mathematical probability, risk exposure and possible damages. In the avalanche bulletin, regularly issued during winter, the avalanche danger is forecasted, not the avalanche risk (SLF, 2018). The individual risk denotes the probability of dying of an individual person per year.

In the following, we first outline the legal situation before we suggest an approach to estimate the avalanche risk for an individual person in a vehicle on a road and to evaluate the individual risk with protection goals as they are currently in use in Switzerland. This approach is illustrated by numbers from a road section in South-Eastern Switzerland.

2. LEGAL SITUATION

The consideration of risk in decisions regarding safety of persons is not part of the Swiss law. According to the guideline for practical work in avalanche safety services, services are obliged to protect persons against negative avalanche impacts with temporary measures, such as e.g. evacuation of persons in buildings and/or closure of roads (Stoffel und Schweizer, 2007). From a legal perspective it is crucial, whether an event with a potentially negative impact can be foreseen or not. Due to the long tradition in avalanche research, the high state of knowledge in snow and avalanche science, available education courses and the avalanche bulletin published twice per day during winter months, avalanches in Switzerland are generally considered as foreseeable. This does not mean that the natural release of a single avalanche is predictable but that time periods with an increased avalanche danger can be foreseen. In terms of temporary mitigation measures this means that measures has to be taken when an object such as e.g. a road section is considered to be at hazard. Therefore, safety services have a duty of care (Anthamatten, 2015) and are obliged to take measures for avoiding damage to persons and assets as far as it is reasonably possible during time periods of increased avalanche danger. When persons are likely to be affected by avalanches on a road section, this endangered road section has to be closed, regardless whether one, ten or hundred persons are endangered. Hence, the number of persons and therefore the risk as mathematical product of probability of avalanche occurrence and the number of persons at risk times the mortality rate under given avalanche impact, may not be taken explicitly into account for safety decisions.

3. RISK CALCULATION APPROACH

We suggest a simple approach to estimate the individual risk of a person crossing an endangered road section and to compare the calculated risk with a defined protection goal. The result should give an idea whether the protection goal for an individual person is violated when the road section he or she crosses, is assessed to be at hazard.

3.1. Calculation of avalanche probability

We assume a typical critical avalanche situation when a safety service judges the avalanche hazard and has to decide whether to close a road section or to leave it open. The safety service faces the question "What is the probability that the road section to be assessed will be hit by an avalanche the next day?" Let's assume a mean return period for this road section of T, then the annual probability becomes $1/T$. We further assume N winter days at which avalanches can occur. The average probability for an avalanche hitting the road the next day becomes

$$P(B) = \frac{1}{T \cdot N}. \tag{1}$$

This is the probability of an avalanche, the safety service has to expect for the next day based on the average return period. We further assume that in a certain percentage of winter days the situation is critical and the service has to judge the safety on the road section. Then the probability for a critical situation the next day is:

$$P(A) = \frac{1}{D \cdot N}. \tag{2}$$

with D denoting the percentage of critical days per winter. We are looking for the probability of an avalanche the next day given that the situation is critical. We apply Bayes theorem:

$$P(B|A) = \frac{P(A|B) \cdot P(B)}{P(A)} \tag{3}$$

where $P(B|A)$ is the probability of an avalanche in a critical situation, $P(A|B)$ is the probability for a critical situation given an avalanches releases (assumption: $P(A|B) = 1$), $P(B)$ is the probability of the avalanche the next day, and $P(A)$ is the probability for a critical situation the next day. Solving equation 3 by inserting the results of equations 1 and 2 yields:

$$P(B|A) = \frac{D}{T}. \tag{4}$$

For seven critical days out of 150 winter days, $D = 0.047$ and $T = 6$ years, $P(B|A) = 0.00783$, i.e. the probability of an avalanche for the next day given the situation is critical.

3.2. Calculation of individual risk

The individual risk of a person on a road section is calculated as (Bründl et al., 2009; Wilhelm, 1999):

$$r_i = p \cdot \lambda \cdot \frac{z \cdot g}{v}, \quad (5)$$

where p denotes the probability of an avalanche, λ the mortality rate of a person in a vehicle, z the number of road section crossings, g the length of the endangered road section, and v the velocity of the vehicle in the road section.

3.3. Evaluation of individual risk

The upper threshold for involuntary individual risks in Switzerland as applied for the evaluation of mitigation measures is defined as $1 \cdot 10^{-5}$ per year (EconoMe, 2018). Distributing this annual individual risk to each winter day, delivers:

$$r_{i,max,d} = \frac{r_i}{N}, \quad (6)$$

with $r_{i,max,d}$ as upper threshold of individual risk per winter day, and N denoting the number of winter days. When the calculated individual risk exceeds the maximum allowable individual risk $r_{i,max,d}$, the protection goal is violated. Assuming N = 150 winter days, we obtain a maximum daily individual risk of $r_{i,max,d} = 6.\bar{6} \cdot 10^{-8}$ per winter day.

4. EXAMPLE FOR INDIVIDUAL RISK ALONG A ROAD SECTION

In the following, we calculate the individual risk of a person crossing a certain road section in the Upper Engadine valley in South-East Switzerland two times per day. The road section is 3.2 km long and is crossed by 17 avalanche tracks with a mean width of g_{mean} = 0.07 km, a maximum width of g_{max} = 0.15 km, and a minimum width of g_{min} = 0.04 km. The mean return period of the avalanches is T = 9.15, with a maximum width of T = 20 and a minimum width of T= 2 years. The velocity of cars is assumed to be v = 40 km/h, and the mortality rate λ = 0.18 in most tracks and 0.4 for three tracks (Wilhelm, 1999). For these three tracks we assume that the vehicle will fall down the embankment due to avalanche impact and we therefore assume a higher mortality rate.

For the calculation of the individual risk we insert the probability of an avalanche expected for the next 24 hours according to equation 4 into equation 5 and with the variables defined above. The resulting individual risk per day range from $8.75 \cdot 10^{-8}$ to $7.50 \cdot 10^{-7}$ with a mean value of $3.02 \cdot 10^{-7}$ per winter day. The sum of individual risk across the whole road section amounts to $5.13 \cdot 10^{-6}$, which represents the risk, a person in a vehicle suffers, when he or she crosses the 3.2 km long road section two times per winter day.

Comparing the individual risk with the individual risk threshold determined with equation 6 ($r_{i,max,d} = 6.\bar{6} \cdot 10^{-8}$), we clearly see that it is exceeded for each of the avalanche tracks (Fig. 1) and for the whole road section.

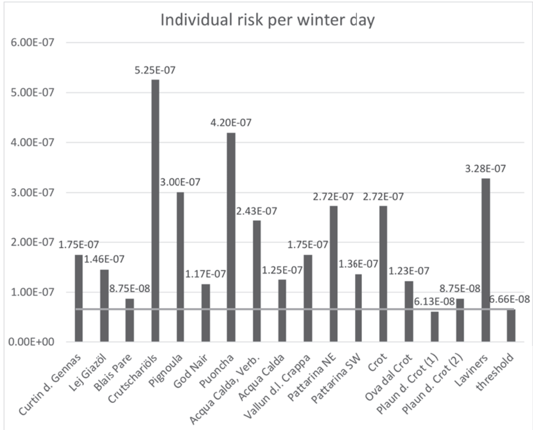

Figure 1: Individual risk in the 17 avalanche gullys in the considered road section. The graph clearly indicates that the daily threshold of individual risk is exceeded by each of the avalanche tracks with one exception (see horizontal line).

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5. DISCUSSION AND CONCLUSION

The calculation of the individual risk resulting from crossing avalanche tracks along a road section shows that the threshold of the individual risk per winter day is exceeded under the assumptions given above. This is in line with the current practice of avalanche safety services, which close a road, when they consider a certain section is at hazard. The evaluation whether a road section is at hazard bases on a careful assessment of available weather and snowpack data and model results, personal observations and experience and the danger level of the avalanche bulletin issued twice per day during winter months by SLF. In periods with a high frequency of vehicles on the road, the resulting high risk might support avalanche safety services in their decision. On such days, the pressure to leave a road section open as long as possible can be high. Since risk may not be a criteria according to the legal situation in Switzerland (see section 2), avalanche safety services have to close a road if they judge this road section to be at hazard. Therefore, from a legal perspective, it does not matter whether 10, 100 or 5’000 vehicles cross an endangered road. The road has to be closed when it is at hazard. Risk in this context can only be an additional information but not a decision criteria alone. This holds for the current legal situation in Switzerland and might not be valid in other countries.

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