THE RELIABILITY OF NORWEGIAN RESCUE MISSIONS FOLLOWING ROAD RELATED AVALANCHE INCIDENTS, MODELLED WITH BAYESIAN BELIEF NETWORK.

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ABSTRACT: In Norway, snow avalanches hitting roads are a considerable safety challenge for the rescue services. Previous studies have given rise to wondering about the rescuers´ levels of exposure to avalanche risk during these missions. A quick and lifesaving response must balance the safety of the rescuers, and their ability to meet both demands constitutes the reliability of the rescue service. All 58 Norwegian rescue service registered road related avalanche incidents in the period of 2010-2014 were included in a study, and 45 out of these 58 incidents were analyzed by the use of organizational risk indicators. Identified risk influencing factors (RIF) and other relevant variables were then included in a Bayesian Belief Network (BBN) in order to model both the associated risk and the overall reliability of the rescue service. The analysis of rescue operations demonstrated high numbers of operational risk assessment deviations related to the alert phase and to the continuous avalanche risk management performed by the rescuers. Qualitative and quantitative modelling showed that rescue management in the alert phase, professional judgement of avalanche conditions, and continuous risk assessment are the most important RIFs to control when aiming at an effective and safe rescue operation.

KEYWORDS: Avalanche rescue, risk management, reliability, risk indicators, Bayesian Belief Networks

1 INTRODUCTION

With a changing climate, and a predicted increase in the frequency of landslides and snow avalanches, the Norwegian avalanche rescue service may face a subsequent increase in road related avalanche incidents, requiring rescue responses in potentially dangerous conditions. In a previous study on snow avalanche risk for Norwegian avalanche rescuers in the period from 1996-2010 (Lunde and Kristensen, 2013), the results indicated that rescuers exposed themselves to high risk in operations following infrastructure related avalanches. However, secondary avalanches caused no physical harm to rescuers in the same period. Thus deteriorated or lack of consideration of secondary avalanche risk might be the typical Norwegian situation.

Road related avalanche rescue is influenced by a number of variables encompassing weather conditions, snow stability, organizational, operational and socio-psychological factors. The combination of uncertainty linked to these variables and the consequences of decisions made by rescuers constitutes the risk model developed in this study.

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Naturally released avalanches is the main challenge for rescuers approaching rescue sites. Different from avalanche accidents in the backcountry, where skier-triggered slab avalanches dominate (Schweizer, 2004), all kinds of avalanches may represent a danger to road traffic.

Uncertainty about snow characteristics will affect the predictability of both avalanche release, the avalanche path and the runout zone. When a series of dry avalanches release at rather unpredictable times, they represent a serious threat to rescuers approaching the accident site.

The aim of the study presented in this paper was to offer a more detailed picture of the rescuers´ exposure to avalanche risk, and to describe the overall risk management. This implied a holistic approach, involving the introduction of organizational risk indicators as a measure of the present and future safety level. In this context, the *reliability concept* is seen as the combination of safety and efficiency, as these aspects cannot be separated in real rescue situations.

A major challenge in evaluating avalanche rescue reliability, is linked to the high number of interacting variables. Risk models may contribute to our understanding of the uncertainties linked to these variables, enabling estimation, communication and management of risk influencing factors.

The research questions to answer were:

Why do avalanche rescuers expose themselves to high risk, and what are the characteristics of these situations?

How can avalanche risk assessments and the reliability of the rescue service be modelled based on historical data and expert judgements?

These research questions required empirical data as well as a theoretical framework for the risk description.

2 METHODOLOGY

Data were collected from police records, and also logs from joint rescue coordination centers (JRCC) in the North- and South-Norway. The material was analyzed to determine the rescuers´ degree of exposure to avalanche danger, avalanche risk assessment activities and risk management.

Avalanche related information was gathered from open sources made available by the Norwegian Meteorological Institute (DNMI), the Norwegian Public Roads Administration (NPRA), the Norwegian Water Resources and Energy Directorate (NVE) and the Norwegian Geotechnical Institute (NGI). The picture was further completed with mass media articles and rescue service reports.

The selection comprised 58 Norwegian road related avalanche rescue operations in the period from 2010 to 2014. These incidents contained 2 fatal accidents, 7 close calls and 49 empty avalanches. 45 of these operations were eligible for detailed analysis. All road related incidents in the long time period from 1996-2010 were included for reference, and to offer a broader description of the phenomena.

The risk level analysis was based on three criteria: the regional avalanche danger level issued by the NVE or own judgement based on weather and snow reports; position of roads relative to avalanche runout zones (NGI avalanche maps and NPRA road data); and the rescuers´ degrees of presence (four levels; 0-3) in areas prone to naturally released avalanches, as reported in logs.

To identify connections between risk influencing factors and unwanted incidents (rescuers exposed in areas prone to secondary avalanches), all cases were analyzed on the basis of a prescription for avalanche risk assessment and risk management. This assessment technique was developed from principles of procedural HAZOP (Willis and Deegan, 1994) and adapted to avalanche response activities. The technique contained the various phases of a rescue operation; alert and dispatch, mobilization of rescuers, travel to the accident site, rescue phase, evacuation and normalization. Deviations from the prescribed assessment procedure was then considered to be a risk indicator.

The overall reliability of the Norwegian avalanche rescue service was modelled using Bayesian Belief Networks (BBN). The aim was to use the explanatory power of the BBN to allow detection of the most important root causes to unwanted incidents, whilst taking into account uncertainty, causal links and the complexity of an avalanche rescue operation. The modelling was performed in the software program Agenarisk (Fenton and Neil, 2013).

The node probability tables (NPT) were completed manually or by the use of the “Noisy-Or-function” (Fenton and Neil, 2013), based on available data and expert opinions. In order to restrict the number of probabilities to elicit, the variables were kept at binary states.

3 RESULTS

The data analysis of occurred events showed that in the long time period from 1996-2014, no vehicles were completely covered by avalanche debris. For those vehicles that ended up in water, traces were always visible, enabling quick locations of the accident sites. All involved passengers were also visible, and subsequently none of the avalanche victims were located by traditional means, like dogs, probes or transceivers. Victims and cars deposited in water were located by divers. The mortality rate in the long time period 1996-2014 was 32,4% (n=34 victims). 47% of the operations took place at night and often in poor visibility.

The width of the registered avalanches, measured on the road, ranged from 10 to 1300 meters, with an average depth of 266 cm (n=29). In 62% of the 45 analyzed cases, the regional avalanche danger was at level 3, considerable (EAWS, 2012).

Table 1: Avalanche danger ratings (n=45)

Avalanche danger level	**Number**
3 - Considerable	28
4 - High	15
5 - Very high	2

In 26,7% of the cases rescuers were exposed in prolonged periods of time in potential runout zones during avalanche danger levels 3-5.

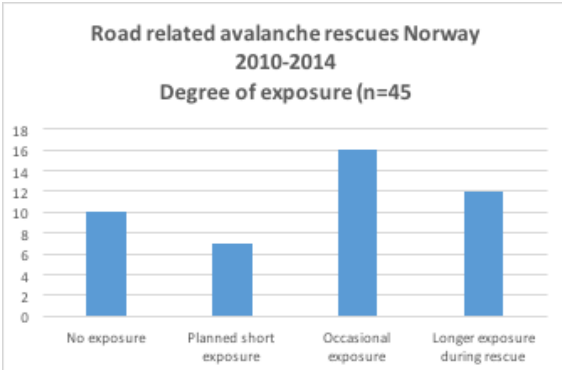

Fig. 1: Degree of exposure

The analysis demonstrated regular deviations in connection with flow of information, competency reflected on complexity, avalanche risk assessments and exposure time. On site over-commitment ("high risk – low gain") was registered in 38% of the cases. Degree of exposure and risk assessment deviations showed a correlation of 0.84, hence assessing risk should be a mandatory part of the response activities.

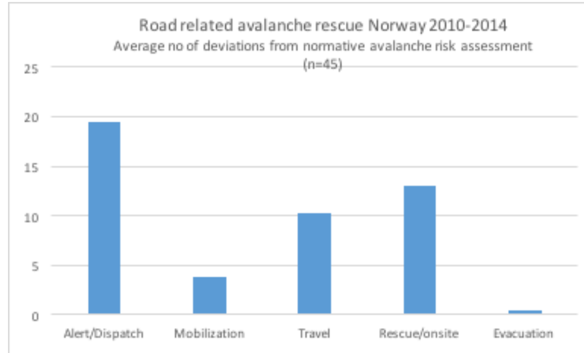

Fig. 2: Deviations – Avalanche risk assessment

Based on descriptive statistics, risk indicators, risk influencing factors and experience, a BBN was constructed consisting of 34 variables, of which 8 synthetic nodes were directly linked to the final node "Efficient & safe operation". Support was also found in Norrington et al´s modelling of the reliability of SAR-operations (2007). Figure 3 shows the network, and variables are explained in table 2. Quantification of the network showed an a priori probability of a reliable rescue response of 63%.

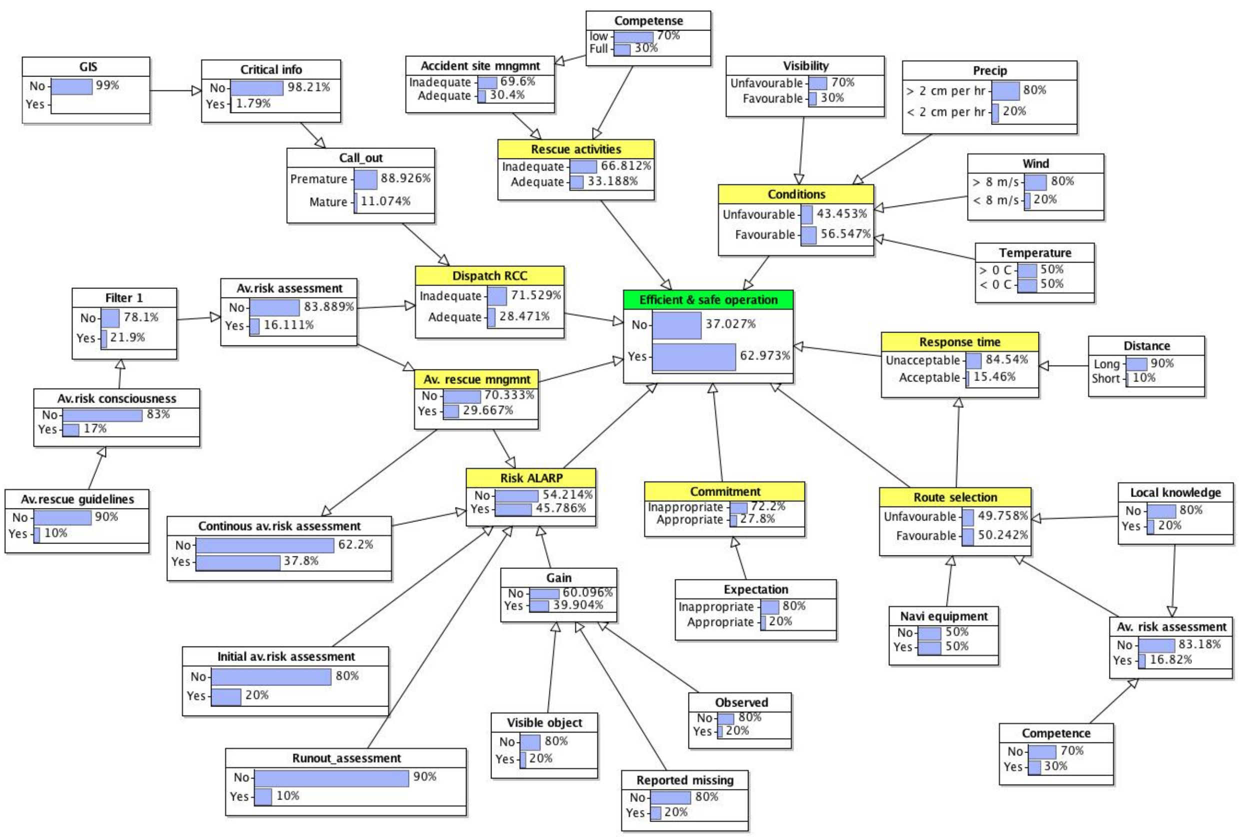

Fig. 3: BBN model of the reliability of the Norwegian avalanche rescue service during road related incidents, in a normal state with apriori probability values.

Table 2: Variables and states: BBN modelling the reliability of Norwegian road related avalanche rescue.

Variables	Definitions	States	
Efficient & safe operation	Optimal rescue operation without unwanted incidents	Yes	No
Conditions	Weather and avalanche conditions	Favourable	Unfavourable
Visibility	Visibility related to avalanche risk assessment	Favourable	Unfavourable
Precip	Precipitation / snowfall per hour	< 2 cm/hr	> 2 cm/hr
Wind	Wind in meters per second	< 8 m/s	> 8 m/s
Temperature	Temperature in degrees Celsius	< 0° C	> 0° C
Response time	Time from first emergency call till rescuers arrive on site	Acceptable	Unacceptable
Distance	Travel distance from responding unit till accident site	Short	Long
Route selection	Route from base till accident site	Favourable	Unfavourable
Local knowledge	Knowledge of avalanche danger zones and paths	Yes	No
Av. risk assessment	Avalanche risk assessment included in route selection	Yes	No
Navi. equipment	Rescuers equipped with and use maps, compass, GPS	Yes	No
Competence	Rescuers can find a safe route in avalanche terrain	Yes	No
Commitment	Balancing safety of rescuers and possibility of saving lives	Appropriate	Inappropriate
Expectation	Rescuers` expectations on possibility of saving lives.	Appropriate	Inappropriate
Risk ALARP	Risk kept As Low As Reasonably Practicable, as a factor of initial and ongoing avalanche risk assessment and realistic gain. Rescuers with safety equipment.	Yes	No
Gain	Probability that somebody are in fact caught by avalanche	Yes	No
Observed	A vehicle is observed caught by avalanche	Yes	No
Missing	A person is reported missing in the area / road stretch	Yes	No
Visible	An object / vehicle is visible on the surface of the avalanche	Yes	No
Initial av. risk assessment	Rescue units assess avalanche danger before travelling towards the accident site	Yes	No
Continuous av. risk assessment	Rescuers assess avalanche risk continuously during travel to accident site	Yes	No
Runout_assessment	Rescuers assess potential runouts for all relevant avalanche paths in the area.	Yes	No
Av. rescue mngment	Avalanche rescue commander and other professional avalanche personnel (e.g. geologists) are involved in the rescue operation, from the beginning till the end.	Yes	No
Dispatch RCC	Emergency call handling, initial avalanche risk assessment and dispatch of competent personnel.	Appropriate	Inappropriate
Av.rescue guidelines	National Guidelines for handling road related avalanche incidents	Yes	No
Avalanche danger focus	Dispatcher awareness of own influence on rescuer safety. Result of National Guidelines and training.	Yes	No
Filter 1	Dispatcher seeks information on weather, terrain, light/visibility and avalanche type. (A. Lunde and K. Kristensen, 2013).	Yes	No
Avalanche risk assessment	Result of Avalanche danger focus and Filter 1; initial sorting of operation in high or low risk. Communicated.	Yes	No
GIS	Geographical Information Systems. Gather relevant information from all available sources.	Yes	No
Critical info	Critical information on known avalanche zones and safe areas is identified and communicated to rescue units.	Yes	No
Call-out	Call-out / dispatch to accident site only after critical information is communicated to rescue units.	Mature	Premature
Rescue activities	Coordinated, safe and efficient rescue activities	Appropriate	Inappropriate
Accident site mngmnt	Competent accident site management	Appropriate	Inappropriate
Competence	Avalanche rescue competence	High	Low

Agenarisk describes testing the model validity by sensitivity analysis (Fenton and Neil, 2013); in this case, determining the influence of the eight synthetic nodes on the main variable. The sensitivity analysis prevents successively putting all variables in a favorable and unfavorable state, to see the effect on the main variable. We see that the probability of a reliable operation ranges from 0.47 (when Risk is not ALARP ("Risk as low as reasonably practicable") to 0.82 when risk is ALARP, with a marginal probability of 0.63 (Fig. 4). By altering the states of the variables, the effect on other variables is modelled. For instance, from a normal state of 63% probability of a reliable operation, there is an increase to 76.5% when dispatch of rescuers is 100% adequately handled. Likewise, positive states for avalanche rescue management and response time will have a considerable impact on the main variable, increasing the reliability to 80.1% and 78.6%.

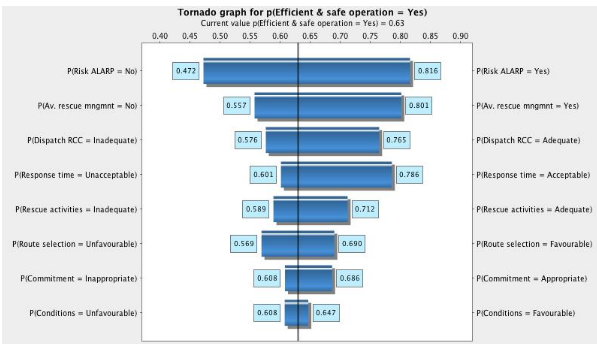

Fig. 4: Variables of greatest influence when rescue operation is reliable.

4 DISCUSSION

4.1 Exposure and avalanche risk assessment

Considering that the number of road related avalanche rescue operations doubled from an annual average of 5.6 to 11.8 when comparing two periods (1996-2009 and 2010-2014), the Norwegian avalanche rescue service needs to focus on its ability to handle these incidents in a safe and efficient manner. The results of this study indicate high-stake searching of avalanches during elevated risk conditions, half of the time in darkness and reduced visibility, and often based on scarce information to justify the efforts.

This apparent over-commitment finds no simple explanation, although external pressure from various sources and an internal moral drive (Ash and Smallman, 2008) might animate rescuers to risk their life in these missions. More research is required to establish which human factors and other mechanisms are acting on avalanche rescuers in "Go – No go" situations, in order to develop organizational strategies to counteract unwanted exposure. This is especially important in rescue situations engaging a mixture of volunteer and professional rescuers, with differing intra-organizational safety regulations.

Figure 2 shows that deviations from the prescribed avalanche risk assessment and management are frequent in the alert and dispatch phase. Of course, this can be seen as a result of the methods used, as the analysis is mostly based on logs from the dispatch centers. However, it may be an expression of a system failure, propagating to later phases (Reason, 1997) and manifesting itself as dangerous acts (prolonged exposure in potential runout zones) in dangerous conditions (avalanche danger levels 3-5). Figure 2 illustrates this point further, as deviations both in avalanche risk assessment and management are registered in approximately 25% of the activities related to the travel and rescue phases.

Interestingly, Leveson (2014) stresses that a focus on deviations from normative procedures diverts the attention from the "performance-shaping context" acting on decisions and individual behavior. This is in line with the views of Rasmussen (1997), pointing at the normality of operating on the limits of normative work procedures. Transferring the ideas of Rasmussen (1997), one may say that the conflicting interests of rescue activities and rescuer safety causes "a systematic migration of organizational behavior toward accident". Taking an organizational view point, Rasmussen argues that "modelling activity in terms of sequences and errors is not very effective for understanding behaviour".

The registration of deviations from the normative avalanche risk assessment as part of the methodology was not to identify individual errors, but a necessary first step to identify RIFs to include in the BBN, and to find support for eliciting node probabilities. We also considered the level at which information flows; activation of trained rescuers; and professional support in avalanche risk assessments, as measures to reduce the uncertainty involved in these rescue operations.

In this respect, the 3x3 method (Munter, 2014) is much advocated to aid initial and continuous avalanche risk assessment, primarily developed for individual's planning winter travel in avalanche terrain. It may as well, though, be a useful tool to aid the gathering and flow of information, starting at the rescue coordination centers, continuing through rescue units to the accident site; all levels participating in reducing uncertainty and backing sound and safe decisions within the scope of normal response time (which was an average of 44 minutes in these cases).

An important starting point, therefore, is risk minded dispatch of rescue personnel, pointing backwards at the organizational and managerial levels. In an ongoing project, we aim at developing valid organizational risk indicators for avalanche rescue in Norway, in which the RIFs will hopefully point us in the direction of a safer rescue practice.

4.2 Bayesian Belief Network modelling rescue

The BBN represents a conglomerate of different managerial levels, actors, functions and tasks, in addition to purely stochastic variables like weather and snow conditions. It offers an evaluation of the reliability of Norwegian road related avalanche rescue on a national level. No doubt, zooming in on a regional scale the network may take other dimensions and give different results.

An overall reliability of a mere 63%, with great uncertainty as to whether risk will be controlled at ALARP level (nearly 50-50), is therefore probably not a fair description of all regions in Norway. However, the BBN reflects findings in logs and reports, where the first responding rescue units often represent ordinary, though professional, emergency services without any formal training in avalanche risk assessment and rescue.

The rescue operations are normally handled by members of volunteer rescue organizations, with a varying competence in avalanche rescue. Although some regions have specialized avalanche rescue teams and snow safety specialists, one cannot systematically expect these complex incidents to be handled by experts. These considerations are reflected in the initial, unconditional probabilities of all parent nodes, except “Conditions” and “Response time”.

In quantifying the BBN, the assigned values are based on a combination of frequencies and subjective judgement (a Bayesian approach), as empirical data is not easily retrieved. This implies assigning values “to the best of my knowledge”. In this approach, the basis for assigning probabilities can be questioned, whereas the value itself is an expression of the uncertainty linked to the state of the event or variable in question.

The variable quantity and quality of relevant rescue data for different regions in Norway is one of the reasons for choosing BBN as the modelling tool, in which the elicitation of expert opinion is crucial. This raises questions of model validity, as to whether the description is useful and recognizable for partners in avalanche rescue. According to Pitchforth and Mengersen (2013:162) validity in the context of BBNs can be understood as “the ability of a model to describe the system that it is intended to describe both in the output and in the mechanism by which that output is generated”. Feedback is in itself a useful validation technique, and this BBN invites further discussions on variables and dependencies affecting rescuer safety. As well as communicating which RIFs to control in avalanche rescue, the interdisciplinary process of developing a regional BBN may contribute to increased safety awareness, in accordance with the elements of collective mindfulness (Weick and Sutcliffe, 2001).

Apart from challenges linked to training and competence, rescuers are obviously faced with tough decisions to make within a limited time frame. A part of this aspect is integrated in the nodes “Expectation” and “Commitment”, and these are as well given a low prior probability of positive influence. This is explained by the fact that most incidents had no victims, and in spite of little information to justify the efforts, rescuers often worked for prolonged periods of time, in adverse conditions.

Braut et al (2012) introduced “Risk Informed Decision Making” (RIDM) as the approach in situations of uncertainty, pointing at the importance of continuous risk assessments based on information processing and identification of critical values. In clarifying alternatives, qualified assumptions on future events should be given in terms of probabilities – a process resembling the quantification of BBNs. BBNs are also mirrored in their concept of risk images rather than risk pictures, underlining the dynamic nature of decision processes.

This relates to the role of situational cues in decision making, noted in this study as e.g. rain on snow, snowdrift, reduced visibility and avalanche activity. Ash and Smallman (2008) observed varying reactions to relevant cues, and found that experts, more often than other fire and rescue team members, judged the risk level to be unacceptable. Human factors in avalanche rescue like the roles of expectation, motivation and commitment, need further clarification.

5 CONCLUSION

The Norwegian avalanche rescue service is vulnerable in its handling of road related avalanche rescue operations. The seemingly excess exposure can be linked to deficiencies in the acquisition and flow of information in the alert and dispatch phase, inadequate deployment of competent personnel, implying inadequacies in the avalanche risk assessment and management.

Modelling avalanche risk assessment and reliability with Bayesian Belief Networks proved promising, as it allowed the integration of both historical data, observations and experience, taking into account the uncertainties linked to these complex rescue operations. The intuitive nature of the graphical model conveys openly all included factors and dependencies, contributing to a transparent analysis and further engagement.

In continuing this project, the integration of BBNs with geographical information systems (GIS) and smartphone technology will be explored in order to evaluate the use of BBN as a decision support tool in ongoing avalanche rescue operations.

CONFLICT OF INTEREST

None of the authors benefit from the production or sale of the mentioned BBN software used in this study.

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