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Rescue performance in Norwegian road related avalanche incidents

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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 concern about the rescuers´ levels of exposure to avalanche risk during these missions. The safety of the rescuers must balance a quick and lifesaving response. The ability to meet both demands constitutes the performance of the rescue service. In the period 2010–2014 the rescue services registered 58 avalanches hitting public roads in Norway. The study reported in this article includes all those events. It explored the characteristics of the rescue missions and which risk indicators that contributed to overall risk to rescuers' health and victims' survival. 45 out of these 58 incidents were analyzed using organizational risk indicators. 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 performance of the rescue service. The analyses showed that rescue management in the alert phase, professional assessment of avalanche conditions, and continuous risk assessment are the most important RIFs to control when aiming at an effective and safe rescue operation. In addition, actions to control undue haste and over-commitment, and enhance risk awareness will contribute to increased safety in this line of rescue work.

1. Introduction

It is predicted that the number of landslides and snow avalanches will increase in Norway as a result of climate change (Bjordal and Larsen, 2009). Consequently, the Norwegian avalanche rescue service will face an increase in road related avalanche incidents, requiring rescue responses in conditions of possible danger. Organized rescue in Norway is carried out as a cooperation between public, voluntary and private organizations. The rescue response to road related avalanche accidents displays great variation in the composition of responding units, preparedness for these specific events, competence of individual rescuers and commanders, available specialized resources and which rescue organization is the first responder. In a previous study on snow avalanche risk for Norwegian rescuers in the period 1996–2010, Lunde and Kristensen (2013) found that rescuers travelled directly to accident sites in high avalanche risk conditions in 26% of all cases. A high proportion of these incidents were in residential areas and on roads. Yet, avalanches hitting access roads or accident sites caused no physical harm to responding rescuers in the same period.

Naturally released avalanches are the main hazards for responding rescuers. Uncertainty about snow characteristics affect the predictability of both avalanche release, the avalanche path and the runout zone. Glassett and Techel (2014, p. 349) concluded about avalanches affecting people along transportation corridors that; *"Secondary or delayed avalanches pose a serious threat to both workers and users especially during times of continuing critical avalanche conditions"*. In Troms in northern Norway, on March 30th 2013, two cars were hit when an avalanche released on persistent weak layers. Both cars, still visible on the snow surface were badly damaged, but no victims were seriously injured. It was, however, difficult to verify how many people were in the area when the avalanche descended, and the police initiated a search operation. Approaching rescuers passed a number of avalanche runout zones on their way to the accident sites and eventually gathered close to several dangerous avalanche paths that had still not released. During the first phase of this operation, some of the rescuers´ cars were blocked by new avalanches in the area, which eventually covered a road stretch of 1300 m.

Performance analysis of avalanche rescue operations requires a holistic approach, which involves the introduction of organizational risk indicators as building blocks of the present and future safety level. In this context, the concept of performance is used to describe how well the avalanche rescue system manages to strike a balance between safety and efficiency. A swift rescue response is required, however mediated by the need to avoid new avalanches both en route and on the accident site. In extreme cases, rescue efforts may have to be postponed for hours and days. The Drümännler accident in Switzerland on January 3rd 2010

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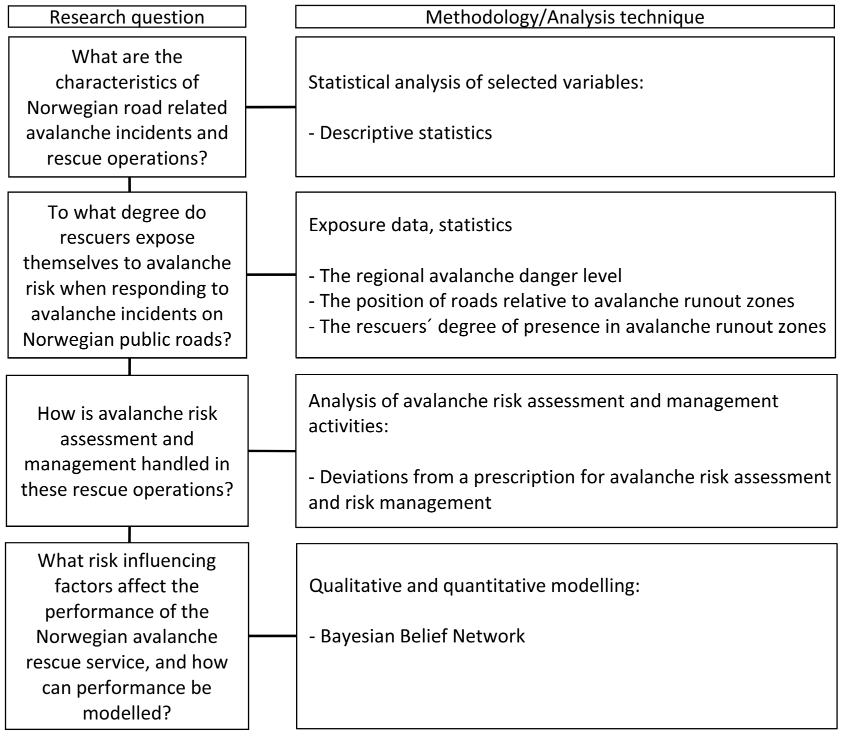

Fig. 1. Research questions and related analyses.

serves as a grave illustration of this issue (Etter, 2010). Seven people including an air ambulance doctor were killed during the rescue mission.

In order to model rescue mission performance we developed research questions that we could investigate, cf. Fig. 1:

The research questions constitute necessary information needed to model rescue performance and are in fact based on all available incidents experienced in Norway. The model is a first approach to provide a tool for rescue services to adapt their missions in accordance with their local conditions and recognized challenges in emerging crises.

2. Methodology and assumptions

In this section, we present the methodology used to study the performance of the Norwegian avalanche rescue service.

2.1. Definitions

- An avalanche incident is any recorded event, with or without confirmed avalanche victims.
- A road or infrastructure related incident is where an avalanche has struck public roads or residential areas.
- Undesirable incidents occur when rescuers are exposed in avalanche runout zones during high avalanche risk conditions.
- An accident is an event with people caught by an avalanche, with three categories; fatal accident, personal injury accident and close call.
- Vehicles and houses involved in avalanches, without passengers or inhabitants directly affected by debris, were counted as close calls.
- Persons directly affected by the avalanche debris were counted as victims.
- Over-commitment is defined as “Situations where rescuers make themselves vulnerable by committing more than is feasible, desirable, expected, recommended or compellingly necessary in the given scenario, and thereby run the risk of life-threatening injury” (Lunde and Braut, 2019).
- Performance is defined as a combination of risk and mission effectiveness.
- ALARP: As Low As Reasonably Practicable, and in proportion to the expected benefit of the rescue activity (HSE, 2018). Management and operators must ensure that that the organization is fit for purpose, the risks are sufficiently low, and that sufficient safety and emergency measures are instituted (Melchers, 2001).

Risk recognition plays a major part in rescue missions. The risk definition controversy attracts many researchers, see discussions in (Braut et al., 2012; Njå et al., 2017; Watson, 1994). One core issue is how to understand and handle uncertainties. Employing risk analysis tools entails the use of models, assumptions and data varying in accuracy and relevance, which further complicates the communication of safety levels.

The purpose of risk assessments in rescue missions is to enable practitioners who act as decision makers to construct risk images based on best possible knowledge, before and during their decision making either on-scene or in operations centres. Risk is constructed by (undesired) events (A), consequences (C), and related uncertainties (U), in which the background knowledge (K) is of vital importance. Risk is commonly communicated as combinations of the concepts probability (or frequency) and outcome (or consequences) and is in our case related to the wellbeing of the rescuers and patient safety.

Response time and rescue capacity are important factors to consider when optimizing the rescue response on the scene of the avalanche. It is a load-response situation as in traditional engineering, but where the stakes are high and conditions uncertain. In order to develop a performance model, we needed to design the research so we could use the best available background knowledge for the modelling work. In this respect we needed to analyse the experience data to reveal influencing factors and tendencies from the real events.

2.2. Database, variables and selection

The Norwegian statistics include all recorded road related

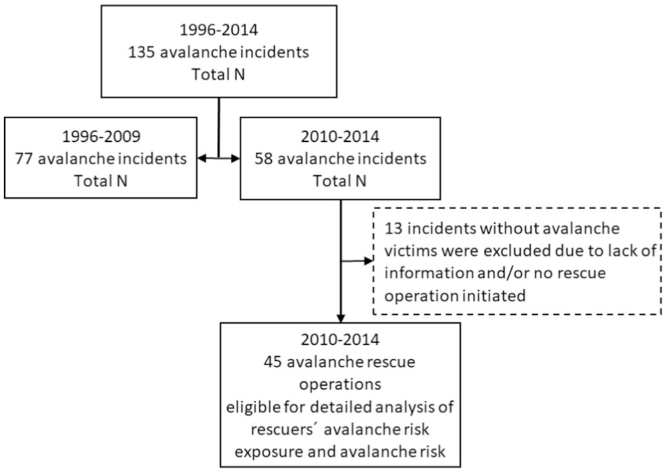

Fig. 2. Flowchart showing the selection of Norwegian road related avalanche incidents included in the study.

avalanche incidents in the period 1996–2014. The primary data source is the Search and Rescue Application System (SARA) at the Joint Rescue Co-ordination Centers in North- and South-Norway. This is an integrated decision support system used to log and share information during rescue operations and to provide a basis for debriefing and reports. The Norwegian Joint Rescue Coordination Centers (JRCC) and The National Police Directorate have authorized the first author to collect and organize data from avalanche rescue logs and reports since 1996. The authorization was linked to internal evaluation of rescue practice and formed a basis for annual reports to the International Commission for Alpine Rescue (ICAR).

83 variables relevant to avalanche rescue have been extracted from the operational data and coded in a Microsoft Excel database, hereafter called the Norwegian Avalanche Rescue Data Base (NARDB). The variables describe time and place, type of incident, type of activity, avalanche size, avalanche victims (no personal information), rescue resources, response time, first responders, methods of locating avalanche victims, type of rescue, weather, regional avalanche danger level, risk management and duration of rescue operations.

As illustrated in Fig. 2, we isolated the two periods 1996–2009 ($n = 77$) and 2010–2014 ($n = 58$), because the information underlying the cases were of different quality. Thereafter, we concentrated in-depth analyses of avalanche risk assessment and management on the last 5-year-period 2010–2014 ($n = 45$). Our aim was to determine the characteristics of Norwegian road related avalanche incidents and to establish a knowledge base for modelling avalanche rescue performance.

2.3. Study design and material

The material was retrospectively analyzed case by case to determine the characteristics of road related avalanche incidents, the rescuers´ degree of exposure to avalanche hazard and their avalanche risk assessment and risk management activities.

2.3.1. Avalanche rescue characteristics – statistical analysis

We obtained select descriptive statistics of Norwegian road related avalanche rescue operations from the NARDB. We used Microsoft® Excel for Mac 2016 Version 16.19 (Microsoft Corporation, 2010, Redmond, Washington) for statistical analyses. To characterize rescue operations and avalanche victims, we calculated frequencies, percentages, mean, median, 25th and 75th percentiles and range. The Welch's *t*-Test was used to compare group means when comparing two different time periods. We considered bilateral *p*-values below 0.05 as significant.

Fig. 3. Example of open source avalanche map of Lødingen, Nordland, North-Norway, provided by NGI. The dark red delineated area represents avalanche release areas (inclinations steeper than 30°). The pink delineated area represents theoretical maximum runout zones. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

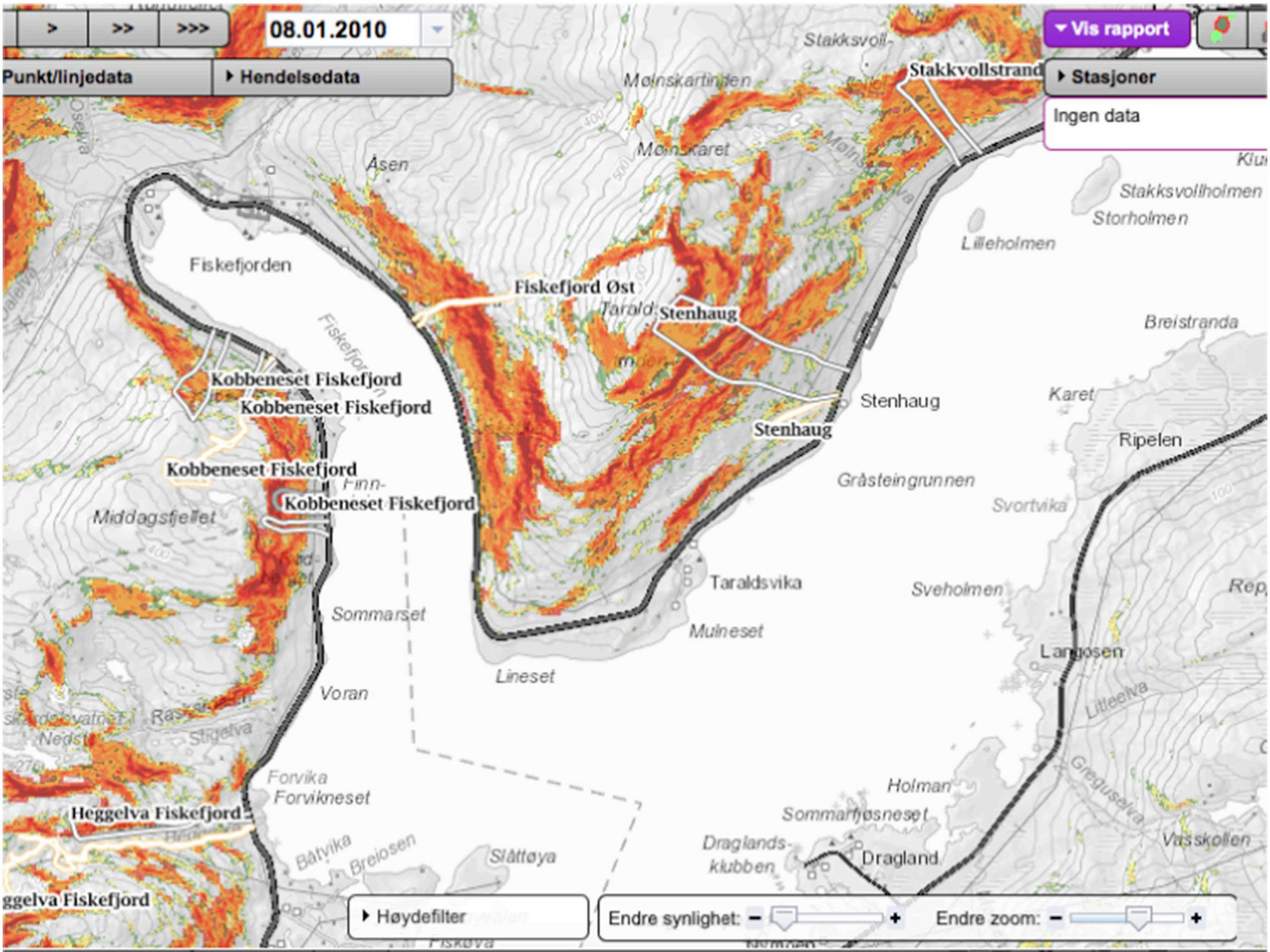

Fig. 4. Example: Screenshot from www.xgeo.no, showing historical avalanche paths (white and yellow delineated polygons) reaching the road in the same area as shown in Figure 3 (Lødingen, Nordland, North-Norway). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.3.2. Avalanche related data materials

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). These sources offered data and maps, detailing topographical (Fig. 3), snow and weather conditions, as well as historical data on avalanches reaching specific road sections (Fig. 4). Specifically, the expert tool and web portal XGEO allowed reconstruction of data related to snow cover and avalanche danger levels (Barfod et al., 2013).

In Fig. 4 the coloured areas indicate steepness. Rescuers approaching from the north will pass 8–10 observed avalanche runout zones on their way to an accident in Fiskefjord/Forvikneset.

2.3.3. Criteria for the interpretation of risk exposure levels

The rescuers` degree of exposure to avalanche risk was based on three criteria:

1. The regional avalanche danger level (EAWS, 2016). The national avalanche forecasts issued by the NVE were available only from 2013 onwards (n = 19). Our assessment of avalanche danger level prior to 2013 (n = 26) was based on an index including 7 class III (LaChapelle, 1985; McClung and Schaerer, 1993) parameters: precipitation (type, intensity and 72 h accumulation), temperature, temperature trend, wind speed and direction. There was no information on class II, snowpack factors. Jürg Schweizer et al. (2003) concluded that field observations of snowpack characteristics showed few deviations from the forecasted danger level, so class II information would certainly have added precision to our assessment. Naturally, recent avalanche activity was always the case in these incidents, (class I data), helping to distinguish between lower and higher avalanche danger levels (McClung and Schaerer, 1993; Techel and Schweizer, 2017).
2. The position of roads relative to avalanche runout zones (Kristensen et al., 2008), as indicated on NGI avalanche maps (NGI, 2018), NPRA road data (NPRA, 2018) and XGEO (Figs. 3 and 4).
3. The rescuers´ degree of exposure in areas prone to naturally released avalanches derived from logs and reports (Table 1). There was no information about where each rescue staff member was at all times, and even small terrain variations could make the difference between a safe and an unsafe area. However, available information on starting points, travel routes and location of rescue sites still enabled conclusions about the degree of presence in avalanche prone road sections. We used four degrees of exposure, as indicated in Table 1.

Table 1
Definition of degree of exposure in areas prone to naturally released avalanches.

0	No exposure
1	Planned, short exposure: A limited number of rescuers are exposed in planned, short-time operations
2	Occasional exposure: Rescuers pass several avalanche runout zones during access and return
3	Prolonged exposure: Rescuers stay and work in avalanche runout zones

2.3.4. Avalanche risk assessment and management activities

To identify links between risk influencing factors and undesirable incidents (rescuers exposed in avalanche runout zones during high avalanche risk conditions), all cases were analyzed on the basis of the normative, chronological order of the rescue phases. The six phases used in this project were: *Alert and dispatch*; *Mobilization of rescuers*; *Travel to the accident site*; *Rescue / Activities on the accident site*; *Evacuation*; and *Normalization*. The normalization phase is not relevant for the models presented in this study and is therefore omitted in the further work.

In order to operationalize important issues in every rescue phase a “procedure-hazop” (Willis et al., 1994) was designed and adapted to avalanche rescue activities. This work was done in the autumn of 2013. Initially, two experts on avalanche rescue reviewed all six phases by using guidewords (e.g. *“too early”*, *“too late”*, *“lacking”*, *“too much”*) to identify hazardous deviations from an optimal operation. The system assessed was the Norwegian Rescue system and its normative procedures and guidelines (Regjeringen, 2018). Later, the analysis that contained the list of deviations was recurrently presented in various annual rescue forums, adjusted and converted to a normative list of expected activities in each rescue phase (Appendix A). Such rescue forums were seminars and courses arranged by the Norwegian Red Cross Rescue Corps, Norwegian School of Winter Warfare and the JRCC with attendees from both professional and volunteer rescue organizations.

The normative list of expected rescue activities presented in Appendix A was used to scrutinize logs and reports from all 45 cases from the period 2010–2014. Compliance with the prescription was assumed to ensure an overall safe performance and, consequently, deviations from the prescribed assessment procedure were considered to form critical features of the emergency response system. The first author analyzed all 45 cases, recorded deviations in each of the phases with a description of the contents and the criticality of the deviation. The assessments were recorded in a data dossier containing detailed evaluation of data sources, their reliability, relevance and validity.

2.4. Factor analysis to extract trends in the material and narrow the critical tasks in the rescue missions

In order to extract tendencies in the rich data material we used a factor analysis in addition to case by case document analysis and interviews. A mixed methods approach and triangulation is advocated by Miles (1994). The exploratory factor analysis (EFA) can also contribute to answering the research questions on the characteristics of Norwegian road related avalanche incidents and rescue operations and the degree rescuers expose themselves to avalanche risk when responding to avalanche incidents.

Factor analysis on binary items has been discussed in the research literature since the 1970-ies (Chapter 8 - Factor Analysis for Binary Data in Bartholomew et al. (2011); Muthen (1978); Muthen and Christoffersson (1981)). Using factor analysis to reveal tendencies in binary variables has not been usual in research designs, but Starkweather (2014) provides a procedure in the Rstudio editor (R Core Team, 2018) that uses the correlation statistic for each pair of variables in the data. The polycor-package contains a function – hetcor - that looks at each pair of variables and computes the appropriate heterogeneous correlation for each pair. The hetcor function is capable of calculating polychoric correlations for binary items. We reduced the huge dataset of 39 binary variables (Appendix A) to 23 because the remaining 16 variables showed no variance ($<$ 2 registered deviations) or were non-measurable (lack of details in logs). Because the data is imported as numeric, we first recoded it as a factor (i.e. categorical) which was done using the sapply-function. When the numeric data was recoded as factors, we proceeded by loading the polycor-package, which contains the hetcor-function. We computed the correlation matrix and assigned that matrix to a new object from the output of the hetcor-function. This is seen as the appropriate correlation matrix, used as the matrix of association for the factor analysis.

The fairly low N (45) is a challenge for factor analysis (Jung, 2013), although “samples somewhat smaller than traditionally recommended are likely sufficient when communalities are high” (MacCallum et al., 2001). Preacher and MacCallum (2002) followed up on this issue and pointed out that N's below 20 led to a marked reduction in factor recovery. The main conclusion, though, was that small N's still allowed satisfactory isolation of factors. The 45 cases in this study make up the entire population of road related avalanches in Norway in the study period and, as such, recover all relevant population factors. Thus, we claim that the material could provide interesting constructs. Applying Starkweather's procedure (2014), the aim was to test our previous interpretations of this data material. The initial correlation matrix formed the basis for a 3-factor solution.

2.5. Qualitative and quantitative modelling

Bayesian Belief Networks (BBN) are considered useful in the assessment of safety and performance in socio-technical systems with many interacting variables (Greenberg and Cook, 2006). We chose the software program Agenarisk (2015) to generate a BBN model of the Norwegian avalanche rescue service. Agenarisk is designed to accommodate *“organizations that need to assess and manage risks in areas where there is little or no data”* (Agenarisk, 2015). This software application includes algorithms that combine probability calculations and graph theory to support risk assessment and decision analysis (Stephenson, 2000). Regional differences in rescue performance can be simulated by entering observations (soft evidence) in the respective variables (Fenton and Neil, 2012, p. 145), thereby achieving locally relevant estimates of performance.

The construction of the BBN followed the seven steps recommended by Fenton and Neil (2012, p. 164):

1: Identify relevant variables.
2: Create a node to each variable.
3: Identify the set of states for the variable.
4: Specify the states for the nodes.
5: Identify variables that require direct links.
6: Create the identified direct links.
7: Specify the node probability table for each node in the BBN.

By placing the variables relative to each other in the graphical structure, we created a generic norm for risk influencing factors and performance in avalanche rescue operations (Fig. 5). As such, *“Bayesian networks may be viewed as normative cognitive models of propositional reasoning under uncertainty”* (Pearl and Russel, 2000, p. 5). To avoid a combinatorial explosion, we restricted the variables to binary states (Fenton and Neil, 2012, p. 215).

The network was simplified by using synthetic nodes defined by their parents. Although a BBN is primarily used to model causal contexts, where the edges indicate causal direction, directional indication

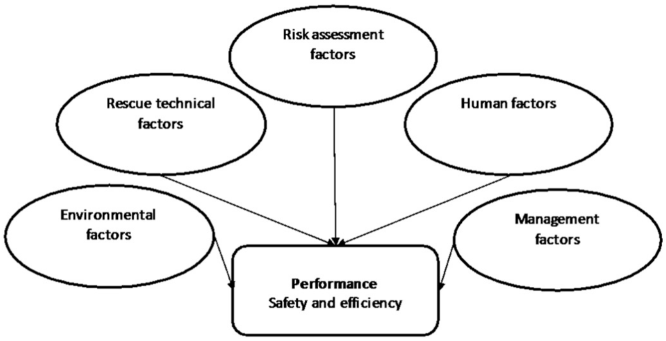

Fig. 5. Generic Bayesian Belief Network. A generic BBN model with factors that may affect performance (safety and efficiency) in the Norwegian avalanche rescue service.

using synthetic nodes will indicate how sub-variables converge to form the synthetic nodes (Fenton and Neil, 2012, pp. 184–188). This structure is also found in Norrington et al.'s (2008) modelling of reliability in maritime search and rescue operations in the UK. In our case, we were left with eight synthetic nodes directly affecting the resultant node; *Efficient and Safe Operation.*

The strengths in the relationships are quantitatively indicated by assigning conditional probability distributions (Fenton and Neil, 2012, p. 141) to all nodes in the BBN. In quantifying the probability distribution tables, the assigned values are based on a combination of frequencies and analyst judgement (Aven, 2012, p. 81) as empirical data is not easily retrieved. In February 2015, we asked groups of regional avalanche rescue specialists from the Norwegian Red Cross Rescue Corps to assign probability of deviance from the prescription for avalanche risk assessment and risk management (Appendix A). Group elicitation expands the knowledge on which to base the probabilities (Vick, 2002, p. 313), and seeks inter-subjective agreement (Aven, 2014, pp. 64–65) - a common opinion among experts. We then applied *"normalized frequencies"* to the variables of the BBN, based on these assignments, historical data and experience, *"to better conform to the circumstances at hand"* (Vick, 2002, p. 127). 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 (Aven, 2012, p. 72).

The node probability tables (NPT) were completed manually or by the use of the "Noisy-Or-function" (Fenton and Neil, 2012), based on the data material and expert opinions. A NPT for the variable *"Rescue activities"* is shown in Table 2.

The Noisy-Or-function reduces the need to elicit a large number of conditional probability values, as the node is given a value according to the probability of the consequence if this causal factor occurs. It requires, however, the determination of an extra probability value ("leakage value"), representing the uncertainty in choice of causal factors, and thus captures the importance of factors not included in the model (Fenton and Neil, 2012, pp. 236–241). This implies that the probability of the consequence will equal the leakage value even if all parent nodes are set to "not true".

Lastly, we applied the Agenarisk sensitivity analysis to test model validity (Fenton and Neil, 2012, p. 264). The sensitivity analysis let us

Table 2
Node probability table for the node *«Rescue activities"*, with parents *"Competence"* and *"Accident site management"*.

"Competence"	Low		Full	
"Accident site management"	Inadequate	Adequate	Inadequate	Adequate
Inadequate	0.95	0.8	0.4	0.01
Adequate	0.05	0.2	0.6	0.99

see the effect of the parent nodes on the resultant node without successively having to put all variables in a favourable and unfavourable state. A graphical output (tornado diagram) allows quick identification of unreasonable influence.

3. Results

3.1. Descriptive statistics

The number of road related avalanche rescue operations doubled from an annual average of 5.5 to 11.6 when comparing the two periods 1996–2009 ($N = 77$) and 2010–2014 ($N = 58$) (p value = .003). In the period 1996–2014, avalanches that hit public roads caused 6 fatal accidents, 4 personal injury accidents and 15 close calls. In these accidents, 11 out of 34 avalanche victims died (mortality rate: 32.4%).

110 recorded avalanche incidents had no victim involvements ($n = 135$). During the five winter seasons from 2010 to 2014, Norway experienced 2 fatal accidents, 7 close calls and 49 non-involvement incidents ($n = 58$). The main characteristics of all Norwegian road related avalanche incidents in the period 1996–2014 are presented in Table 3.

In the longtime period 1996–2014 (n = 135), no vehicles were completely covered by avalanche debris. In this material, we saw no indications of a relationship between degree of coverage of avalanche struck vehicles, avalanche danger level and the reported depth of avalanche debris on the road. 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 required location by traditional means, like dogs, probes or transceivers. Victims and cars deposited in water were located from boats or by divers.

In 28 (62%) of the 45 analyzed cases in the period 2010–2014, the regional avalanche danger was at level 3, considerable (EAWS, 2016). Of the remaining 17 incidents in the study, 15 were at danger level 4 and 2 were at danger level 5.

3.2. The rescuers` degree of exposure to avalanche risk

In 12 rescue operations ($n = 45$) (26.7%) rescuers stayed and worked in runout zones during avalanche danger levels 3–5. In 16 of the operations (n = 45) (35.6%) rescuers were occasionally exposed in runout zones as they travelled to and from accident sites. In 7 of the 45 operations (15.6%), following planning, rescuers deliberately entered avalanche prone areas in swift search operations to check whether vehicles were covered by avalanche debris. We found no exposure of rescue personnel in 10 of the 45 rescue operations (22.2%).

3.3. Avalanche risk assessment and management activities

The analysis of deviations from a prescription for avalanche risk assessment and risk management (Appendix A) gave the following average number of deviations in each rescue phase: Alert/Dispatch: 19 (n = 45) (42.3%), Mobilization: 4 (n = 45) (8.9%), Travel: 10 (n = 45) (22.2%), Rescue: 13 (n = 45) (28.9%) and Evacuation: 1 (n = 45) (2.2%). A figure showing the detailed distribution of deviations can be found in Appendix B.

The rescuers´ degrees of exposure and risk assessment deviations showed a correlation of 0.84.

3.4. Factor analysis

We examined the correlation matrix derived from registered deviations and found that all but one *("Rescue units are informed about the time of the accident"*) of the 23 items correlated with one or more factors by > 0.3. The result indicated a sufficient degree of collinearity between the variables. The Kaiser-Meyer-Olkin (KMO) test, which returns

Table 3
Select statistics of Norwegian road related avalanche incidents in the periods 1996–2009 and 2010–2014.

Search and rescue statistics	1996–2010 (*n* = 77)	2010–2014 (n = 58)
Response time in minutes, median (n^{obs}, 25th–75th percentiles)	–	34 (30, 26.3–48.0)
Duration of operations, hrs, median ($n^{obs,}$ 25th–75th percentiles)	–	2,3 (40,1.5–3.6)
Time of day between 1800 and 0600[1] h, n (%)	34 (44.2)	23 (39.7)
Debris width on road in m., median (n^{obs}, min, max)		60 (41, 10, 1300)
Debris depth on road in cm., median (n^{obs}, min, max)	–	250 (29, 2, 1000)
Most frequent first responder[2]; Police patrols, n (n^{obs} %)	14 (66, 18)	25 (45, 56.0)
Police (accident site leader) present, n (%)	47 (61.0)	42 (72.4)
Rescuers on site, median (n^{obs}, 25th–75th percentiles)	6 (25, 2.0–14.5)	6 (32, 4.0–20.0)
Rescue dogs present on site, n (%)	40 (51,9)	23 (51,1)
Air rescue helicopters activated / en route, n (%)	36 (46,8)	35 (60,3)

obs, Number of observations. n^{obs} is the number of rescue operations where this information was provided.
1. The time of day with least daylight, early winter; darkness, in spring; short time of darkness.
2. Organized rescue.

Table 4
Factor loadings, sorted by Factor I, in decreasing order. Note: Factor loadings < 0.5 are suppressed and factor loadings ≥ 0.60 are in bold to highlight items showing a strong connection with the factor of interest. The 3 latent factors were named: I: Degree of Avalanche risk awareness (α = 0.85) II: Degree of commitment (α = 0.85) and III: Degree of application of risk reduction measures and mitigation (α = 0.86).

Item no.	Item	Factor I	Factor II	Factor III	Communality
3a1	Avalanche risk assessment is performed (“Nowcast”)	**0.89**			0.89
1a2	Dispatcher gathers sufficient information about the situation and the involved victim/s	**0.87**			0.92
4a1	Avalanche risk assessment is performed (“Nowcast”)	**0.86**			0.83
4a2	Rescue unit assesses maximum avalanche runouts in the accident area	**0.76**		**0.63**	0.99
2b1	Sufficiently competent rescue personnel with respect to complexity	**0.74**	**0.65**		0.98
1a3	Dispatcher has available standardized guidelines for gathering avalanche specific information	**0.71**			0.67
1b2	Dispatcher announces an initial assessment of avalanche risk in the area	**0.63**	0.51	0.53	0.93
1c2	Avalanche rescue specialist is appointed in the alert phase	**0.60**	0.54		0.99
1b1	Dispatcher gathers critical information before alerting and dispatching rescue units	**0.60**	0.52	0.59	0.68
2b7	Not too many rescuers dispatched (adjusted to situation and risk level – reduce exposure)	0.57	0.56		0.50
3a3	Rescue unit does not cross potential runout zones during elevated avalanche danger levels	0.56	0.50	0.54	0.86
1a1	Dispatcher asks about avalanche risk, weather, terrain, light/visibility, type of avalanche		**0.65**		0.59
1a4	Dispatcher interviews accident reporter / witness to gather avalanche specific information		**0.82**		0.74
1c1	Dispatcher offers sufficient information to rescue units		**0.72**		0.57
1c3	Rescue units are informed about the time of the accident.				0.78
1c4	Rescue units are offered information on local conditions (terrain, snow and visibility)			**0.76**	0.75
2b2	Travel to accident site only after rescuers are adequately informed and coordinated		**0.68**		0.59
2b4	No overcommitment. Level of motivation adjusted to situation and possible gain		**0.61**		0.45
3a5	Adequate avalanche risk assessment		**0.78**	0.57	0.92
3b1	Rescuers are not travelling on the ground when helicopter is available and safer			**0.90**	0.86
3b2	Avalanche risk assessment is performed continuously when travelling to the accident area				0.26
4a3	Rescue units do not spend too much time on their way to, and/or in the accident area		**0.77**		0.89
4a4	No overcommitment. Justified and reasonable time and effort spent in the accident area		0.56		0.59
	SS loadings	**7.21**	**6.39**	**3.64**	
	Proportional variance	**0.31**	**0.28**	**0.16**	
	Cumulative variance	**0.31**	**0.59**	**0.75**	

a value between 0 and 1 to indicate the suitability of the data for factor analysis, showed a mediocre (0.64) value, weakly indicating a factorable dataset. The Bartlett's test of sphericity was not significant ($\chi 2 = 281.337$, $p = .77$), failing the assumption of equal variance. Lastly, the mean level of communality, which is the proportion of variation explained by the model, was 0.75 (σ = 0.2). This value indicates that the variables are fairly well explained by the factors. Thus, the exploratory factor analysis supported the isolation of 3 latent factors (Table 4), subsequently denoted: I: *Degree of avalanche risk awareness* (α = 0.85); II: *Degree of commitment* (α = 0.85), and III: *Degree of application of risk reduction measures and mitigation* (α = 0.86). The Cronbach's alpha coefficients (Cronbach, 1951) are all above 0.70, which indicate that the items show good internal consistency. The relatively high values give rise to concern that some items are redundant and test the same phenomenon, although the limit for such an assumption is commonly set to > 0.90 (Tavakol and Dennick, 2011).

Items *“No assessment of maximum avalanche runouts”* and *“Lack of competent rescue personnel”* cross load ≥0.6 on factors I and II, suggesting that these items may measure both concepts. Considering loadings between 0.5 and 0.6, the boundaries between factors are blurred, especially in items related to the Alert and dispatch phase *“Dispatcher does not announce an initial assessment of avalanche risk”*, *“Avalanche rescue specialist is not appointed in the alert phase”* and *“Dispatcher does not gather critical information before alerting and dispatching rescue units“*.

These constructs reflect the findings presented in section 3.3, Avalanche risk assessment and management activities (Appendix B), in that we see an aggregate of covariance in items related to dispatchers´ and rescuers´ activities to mind and handle avalanche risk in the various phases of rescue operations. In this respect, factor I and II load quite substantially, whereas factor III, does not stand out very clearly, loading strongly 0.90 on the item *“Rescuers are not travelling on the ground when helicopter is available and safer”*, but rather weakly on another important risk reducing measure; *“Rescue unit does not cross potential runout zones during elevated avalanche danger levels”* (0.54). Further, factor III would benefit from including other items that are not in the list of items in Table 4, to strengthen the risk reduction and mitigation profile, but these loadings were below 0.5.

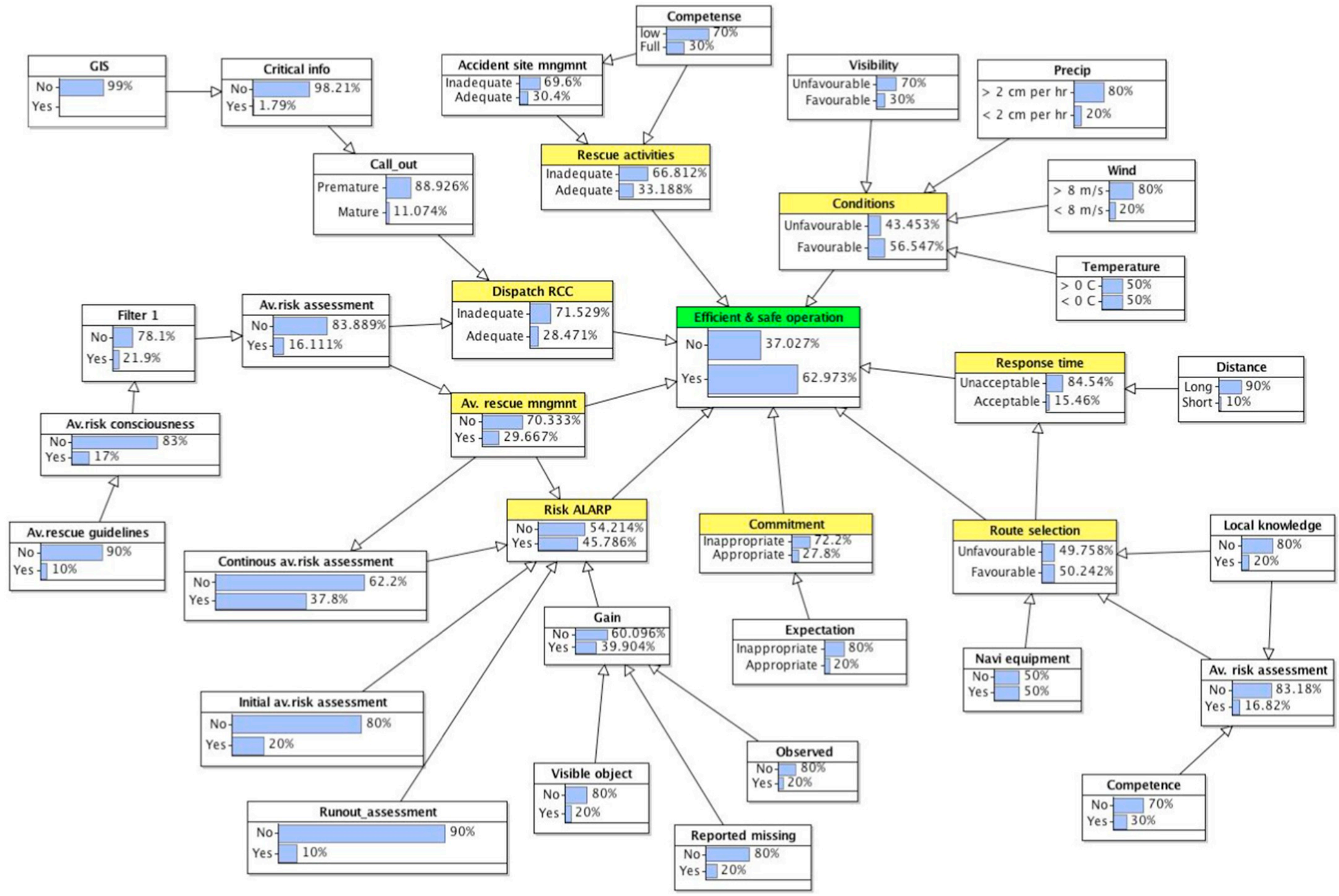

Fig. 6. BBN model of the performance of the Norwegian avalanche rescue service during road related incidents, in a normal state with apriori probability values.

3.5. Qualitative and quantitative modelling - Bayesian Belief Network

Based on the normative list of expected activities in each rescue phase (Appendix A), descriptive statistics, identified risk indicators and input from experts on Norwegian avalanche rescue operations, a BBN was constructed consisting of 34 variables (Fig. 6 and Table 5). Eight synthetic nodes (yellow label in Fig. 6) were directly linked to the final node *"Efficient & safe operation"* (green label in Fig. 6).

When weighting the influence of the synthetic nodes on the outcome variable by the Noisy-Or function (Fenton and Neil, 2012), most weight was assigned to the *"RISK Alarp"* variable (0.6) and the least weight to *"Conditions"* (0.1). The leakage value was set to 0.1. The resultant a priori probability (normal state) of a safe and efficient rescue response was 63%, i.e. in 6 out of 10 rescue operations following road related avalanches, the Norwegian avalanche rescue service demonstrates an acceptable performance.

We evaluated the influence of the eight synthetic nodes on the main variable by sensitivity analysis (Fig. 7) (Fenton and Neil, 2012, p. 264).

The variable of greatest influence on Norwegian avalanche rescue performance is the ability of rescuers to operate within tolerable risk limits (Risk ALARP). This ability is seen as a result of pertinent avalanche risk assessments in all phases of the rescue operation and possible gain for avalanche victims. The probability of a safe and efficient operation ranges from 0.47 when risk is not kept as low as reasonably practicable to 0.82 when risk is within acceptable bounds (no unwarranted exposure of rescue personnel). Dispatch and avalanche rescue management are both considered important factors in moderating the rescuers ability to balance risk and benefit. From a normal state of 63% probability of a safe and efficient 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%.

In January 2017 we used the model to simulate avalanche rescue performance in a region of Western Norway, in an inter-organizational pre-season avalanche rescue meeting (Lunde et al., 2017). Prior to the meeting we elicited relevant input from local rescue specialists and then entered soft evidence (Fenton and Neil, 2012, p. 145) in accordance with their advice. The result, which showed an increase in performance from the overall national level of 63% to a regional performance level of 81%, illustrated how BBN modelling may be used to identify weaknesses and strengths in local emergency preparedness. *"In all of this, the whole exercise of using probability is fundamentally diagnostic in nature"* (Vick, 2002, p. 400).

4. Discussion

4.1. Characteristics of road related avalanche incidents

Based on historical data it seems unusual for a vehicle struck by snow avalanche to be totally covered by debris, and this seems to be independent of avalanche danger level and possibly avalanche size. This observation is uncertain, both due to inconsistent reports of avalanche debris on the roads and the inherent uncertainty in assessing avalanche danger levels (Techel and Schweizer, 2017). Schweizer et al. (2018) found no relation between avalanche size and avalanche danger level, which could explain the lack of dependency between coverage and avalanche danger level. Another plausible explanation in those cases where vehicles float freely in moving debris is the effect of inverse segregation (Kern et al., 2001), i.e. an upward sorting of larger particles

Table 5
Variables and states: BBN modelling the reliability of Norwegian road related avalanche rescue.

Variables	Definitions	States	
Efficient & safe operation	Optimal rescue operation without undesirable incidents	Yes	No
Conditions	Weather and avalanche conditions	Favourable	Unfavourable
Visibility[a]	Visibility related to avalanche risk assessment	Favourable	Unfavourable
Percip[a]	Precipitation / snowfall per hour	< 2 cm/h	> 2 cm/h
Wind[a]	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[b]	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 toward 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 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.	Adequate	Inadequate
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[c]	Dispatcher seeks information on weather, terrain, light/visibility and avalanche type.	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	Adequate	Inadequate
Accident site mngmnt	Competent accident site management	Adequate	Inadequate
Competence	Avalanche rescue competence	High	Low

[a] With reference to (Lied and Kristensen, 2003).
[b] With reference to the probability of survival for totally buried avalanche victims (Brugger et al., 2001), distance allowing a rescue response within 15 min is short, otherwise long.
[c] With reference to (Kristensen et al., 2007). Filter 1 is the first information gathered by dispatch centers.

in granular flow, irrespective of density. Of course, micro-terrain features may trap vehicles, and one may expect that such scenarios are sought avoided by careful road planning. Considering the construction of modern cars and the passengers` regular use of safety belts, avalanche victims will most likely be stuck inside the vehicle. This limits the search and rescue task to localizing the car and freeing the victims. Implicitly, crew demanding and time-consuming operations to search for non-confirmed victims outside of vehicles are examples of high risk – low gain activities and should be reduced to a minimum. There exist very few examples containing other road users, such as motorbikes, cyclists or pedestrians struck by snow avalanches.

4.2. Rescuers` exposure to avalanche risk

Two-thirds of the rescue operations took place during considerable avalanche danger. This proportion of incidents in danger level 3 conditions coincides with recent NPRA statistics on road related avalanches (Orset et al., 2017) and an earlier study by Hohlrieder et al. on avalanche rescue missions in Austria (2008). According to the European avalanche danger scale, naturally released avalanches are increasingly frequent at danger levels 3–5 (EAWS, 2016). Jürg Schweizer et al. (2003) found that observed avalanche activity alone correlated poorly with the lower avalanche danger ratings. In a more recent study by Schweizer et al. (2018, p. 1), they found that *"the frequency of natural avalanches strongly increases with increasing danger level"*.

The probability of secondary avalanches in adjacent paths is typically assigned a value between 0.03 and 0.30 (Hendrikx et al., 2006). Kristensen et al. (2003), used a snow avalanche probability of 0.5, and presented two representative calculations of the probability of moving and stationary cars being hit by "neighbour-avalanches", showing values of 0.0001 and 0.15. Kristensen and Harbitz also proposed that the probability of a new avalanche in the vicinity of the first may rise to 0.90 in case of confirmed recent avalanche activity, which is normally the case in road related avalanche rescue operations.

We made no attempt to calculate the risk level for individual rescuers in these operations. E.g. calculating the Avalanche Hazard Index (Schaerer, 1989) for all the road sections of these 45 cases would be a formidable task, and the required number of uncertain assumptions would most likely compromise the validity and usefulness of the results. The use of expected values to describe risk for rescuers is also questionable, as this metric does not account for outliers, i.e. extreme events. This "can seriously misguide decision-makers in practice" (Aven, 2014, p. 25). For our purpose of identifying undesirable incidents, a semi-quantitative approach was sufficient.

Even a low probability of release and a statistically low risk of being hit by an avalanche during a rescue response may be considered unacceptable, taking into account the high mortality rate in road related avalanche accidents (0.32) and that safety is top priority for rescuers (Blancher et al., 2018, p. 4; Garrison, 2002, p. 634; Regjeringen, 2018).

Given the low predictability of snow avalanches (Jürg Schweizer,

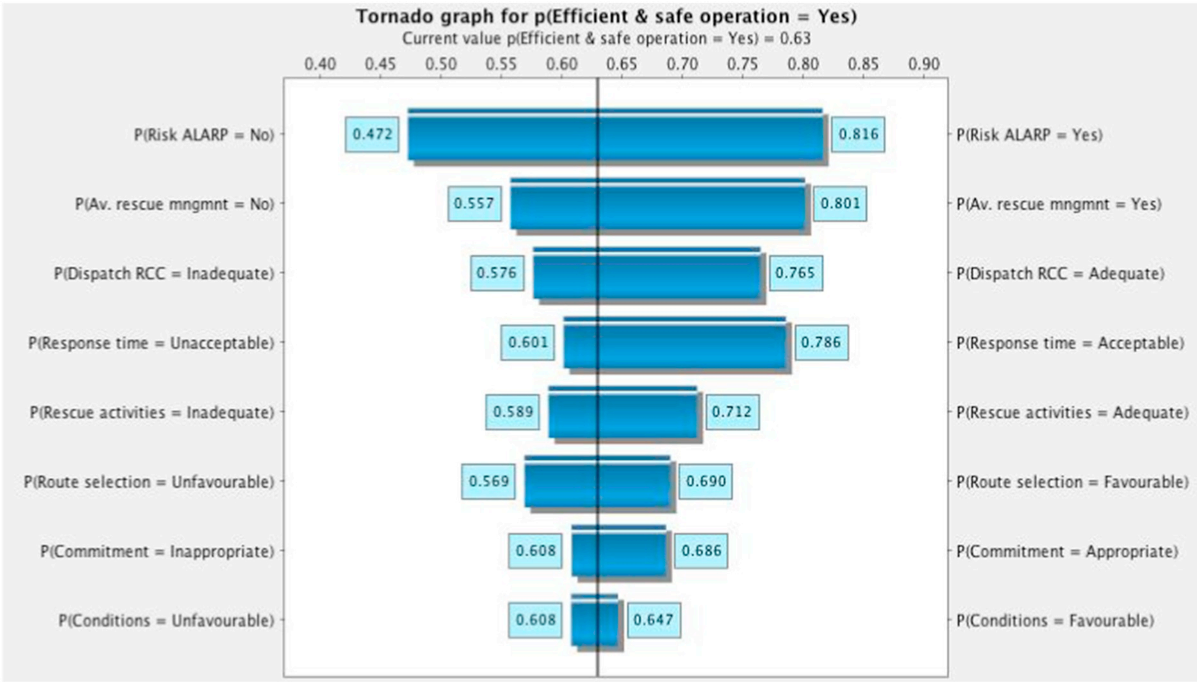

Fig. 7. Sensitivity analysis. Variables of greatest influence are indicated by the length of the horizontal bars. The vertical line indicates the marginal probability for an efficient and safe operation (0.63).

2008), only a terrain-based approach (Lied and Kristensen, 2003, p. 119) of total avoidance of release zones and only limited and controlled exposure in runout zones is recommended for the rescue service (NRR, 2012). This is reflected in both the prescription for avalanche risk assessment and management (Appendix A) and in the Bayesian network (Fig. 6 and Table 5).

As the rescuers` exposure in avalanche terrain was quite high, in avalanche danger levels 3–5, and many rescue responses took place in darkness and reduced visibility, we raise the question whether the Norwegian avalanche rescue service is working safely in this type of rescue operations. Since a high percentage of call-outs seemed unnecessary (8 out of 10 avalanches had no victims) and risk assessment and management activities were missing or inadequate (section 3.3), we see this as a sign of over-commitment (Ash and Smallman, 2008). More research is needed to establish which mechanisms are acting upon avalanche rescuers in "Go – No go" situations. This is especially important in rescue situations engaging a mix of volunteer and professional rescuers, with differing intra-organizational safety regulations.

4.3. Avalanche risk assessment and management

We considered information flow, activation of trained rescuers and professional support in avalanche risk assessments as measures to reduce the uncertainty involved in these rescue operations. An important starting point, therefore, is to introduce a risk minded dispatch of rescue personnel. This aspect is included in several nodes of the BBN, especially *"Dispatch RCC"*, *"Av. rescue management"*, *"Risk ALARP"* and *"Rescue activities"*. Deviations from the prescription for avalanche risk assessment and management are frequent in the alert and dispatch phase. The regularity of these deviations may be an expression of a system failure, e.g. it is not specified as a regular task at dispatch centers to gather and share information on avalanche risk. We assume that early information about local weather, terrain, snow and avalanche conditions (Kristensen et al., 2007) will increase the collective avalanche risk awareness (K. E. Weick et al., 2008) and reduce the possibility of undesirable incidents. Bründl and Etter (2012) also recommend an early assignment of mission tendency as low or high risk. Therefore, a failure to trigger avalanche risk awareness can propagate to later rescue phases (Reason, 1997) and manifest itself as dangerous acts (prolonged exposure in runout zones) in dangerous conditions (avalanche danger levels 3–5). Deviations in accomplishing avalanche risk assessment and management occurred in one quarter of the activities related to the travel and rescue phases. We link this observation to our interpretation of the factor analysis. These factors were not decisive to the modelling of performance in Norwegian avalanche rescue operations but supplemented our validation of the variables and probabilities included in the BBN.

Leveson (2011) 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 behavior"*. One part of the performance-shaping context is the initial handling of road related avalanche incidents and the sense of urgency which dispatch centers impose on both the rescue organization and individual rescuers. We think that further research into factors that govern choice of behavior in avalanche rescue missions is needed, in which the concept of over-commitment and the perspectives on naturalistic decision making could provide interesting knowledge.

4.4. Bayesian Belief Network modelling rescue performance

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 performance 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. This is also reflected in the feedback gained from fellow rescuers on presenting the model, offering insightful suggestions on new variables and adjustments of the variable ratios (Lunde et al., 2017). In our approach, the knowledge base for assigning probabilities can be questioned, whereas the value itself is an expression of our uncertainty about the state of the event or variable in question. In the understanding that all probabilities associated with an uncertain event are conditional upon the context of the incident, we must also be open to changing our perception of the given probability in meeting new knowledge and new assumptions. This is the basis for structuring and quantifying phenomena in the Bayesian network.

BBN as the modelling tool is especially powerful when we have a mix of qualitative and quantitative data (Fenton and Neil, 2012). The validity of the model, both causal interpretations and generalizability, can be questioned. The intention with such models is not to be considered as the truth or being the correct model. It is a representation of the data material and the expertise of the analysts involved. Thus, rescuer's participation and critical reflections are assumed in all contexts using the model. According to Pitchforth and Mengersen (2013, p. 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 (K. Weick and Sutcliffe, 2001).

Our results show a 63% probability of safe and efficient avalanche rescue performance. The considerable uncertainty as to whether risk will be controlled at an ALARP level (nearly 50–50), is 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 systematic formal training in avalanche risk assessment and management. This is exemplified by the fact that police patrols were the first to respond in 56% of these 58 cases. Also, incident site commanders are not always present to support the first responding rescuers. The rescue operations are normally handled by members of volunteer rescue organizations, also 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 in the presented BBN, except *"Conditions"* and *"Response time"*.

Apart from challenges linked to training and competence, rescuers are obviously faced with tough decisions to make within a limited timeframe. Both internal motivation and external pressure, e.g. from witnesses, employers and mass media may influence their decisions (Ash and Smallman, 2008; Blancher et al., 2018, p. 4; Winn et al., 2012, p. 81). This aspect is integrated in the nodes "Expectation" and "Commitment", and these are as well assigned a low probability of being kept at an appropriate level. This is explained by the fact that most incidents had no victims, and in spite of little information to justify the efforts, rescuers often responded directly and swiftly to the accident site, and worked for prolonged periods of time, in adverse conditions (Appendix A, ID nr 4a4).

Braut et al. (2012) introduced *"Risk Informed Decision Making"* (RIDM) as the approach in situations of uncertainty. They pointed 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, which underlines 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 studies. Against this background we also see the control actions by dispatchers as necessary mechanisms for adjusting expectations, sense of urgency and safety mindedness.

4.5. Limitations

The Microsoft Excel data base is developed in retrospect and some of the information has been interpreted from free text fields. Even if the informational quality of registration has increased over the years, it is still variable due to both inter-operator differences in registration of relevant details and inter-regional differences in how to conduct and document rescue activities. This may have affected the level of detail in which risk assessment and management activities were logged and consequently how the rescue situation was interpreted by the analyst. Also, the analysis was performed by the first author only. Since some of the cases required a certain degree of interpretation, the study would probably have benefited from repeated measurements. Nonetheless, all analyses were documented in data dossiers to ascertain consistency and to allow comparisons to be made.

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. The method used to evaluate rescuers´ exposure in avalanche prone terrain could be included in emergency planning and preparations for infrastructure related avalanche rescue operations, specifically directing rescuers to safe places along access routes.

Modelling avalanche risk assessment and reliability with Bayesian Belief Networks proved promising, as it allowed the integration of both historical data, observations and experience, whilst taking into account the uncertainties linked to these complex rescue operations. The intuitive nature of the graphical model conveys openly the included factors and dependencies, contributing to a transparent analysis (Straub, 2005). As such, the BBN allowed avalanche risk management to *"be modelled by a cross-disciplinary study, considering risk management to be a control problem and serving to represent the control structure"* (Rasmussen, 1997, p. 183). The model itself also encourage a critical reflexive stance to risk that imply continuous knowledge generation.

The resulting probability of a safe and efficient rescue operation reflects the variability in performance, pointing at important factors to control in order to ensure an acceptable level of response throughout the country. Over the years, much attention has been paid to response time, in view of the poor prognosis of totally buried avalanche victims. The results of this study indicate a need to focus on factors that allow rescuers to remain in control of their own safety. Balancing the need of patients against rescuer safety implies controlling undue haste and over-commitment, enhancing risk awareness and allowing time for necessary avalanche risk assessment and management. Considering safety as a control problem (Leveson, 2011), managerial levels need to engage in control actions that stimulate and support both safety and efficiency.

Conflict of interest

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

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Appendix. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.coldregions.2019.04.011.

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