Risk management in Norwegian avalanche rescue operations

Managing uncertainty, complexity, over-commitment and the long-term monitoring of accident risk.

by

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Being a volunteer rescuer is not a paid job. It is a mild form of mental disorder – and it is chronic. I am wholeheartedly grateful to my wife Elisabeth, who has always been supportive and caring. Even in my late blooming as an academic, she keeps on cheering. Perhaps it is because of her background as volunteer rescuer in the Red Cross? Our children, Kirsti, Sondre and Ingvild, who in their early years did service as "bodies" for avalanche dog training, have later become our trusted advisors in many aspects of life, also rescue and research.

All over the country, I could point at rescuers who have made a difference by sharing their knowledge and experience. They have created the curiosity I needed to embark on the lane of research.

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Summary

Introduction: Avalanche incidents commonly take place in adverse environmental conditions, and the expected survival time of avalanche victims is short. These situations require an immediate rescue response, which may pose a serious challenge to the safety of both rescuers and avalanche victims. Historically, the Norwegian rescue service has experienced few serious accidents, but undesirable incidents where rescuers are dangerously exposed in avalanche runout zones seem more frequent. Risk management in the avalanche rescue service is multifaceted, influenced by its multi-organizational structure. Individuals acting in this socio-technical rescue system are easily caught between two imperatives: saving lives and staying alive. The aim of risk management is to maintain equilibrium in rescue commitment. This project analysed whether the Norwegian avalanche rescue system is correctly balanced to withstand the extra load of common risk influencing factors in rescue operations.

Aim: The fundamental aim of this thesis was to contribute to new knowledge on factors that are important for risk management and performance in the Norwegian avalanche rescue service.

Methods: Mixed methods research was applied to answer the specific research questions. This implied multiple research activities in a combination of quantitative and qualitative methodologies. Study number 1 was a retrospective study to characterize Norwegian avalanche incidents and rescue response (Paper I). A comprehensive study comprising avalanche rescue statistics, cross-case analysis, factor analysis and risk modelling was conducted to gain insight into avalanche rescue performance (Paper II). In a phenomenological study to explore the concept of overcommitment, nine air ambulance crews from five bases took part in focus group interviews (Papers III and IV). Lastly, a systemic safety analysis was conducted in two separate seminars,

supported by the insight of six experts in Norwegian avalanche rescue operations (Paper V). The thesis itself is a cross-paper synthesis of results.

Results: The studies returned results which contribute to justified beliefs about patient and rescuer safety in Norwegian avalanche rescue operations.

Paper I: Norwegian avalanche rescue statistics from the periods 1996-2017 and 2010-2017 showed that 75% of avalanche victims were already located and recovered by the time organized rescue units arrived at the accident site. Of the remaining 25% not recovered by companion rescuers, organized rescuers located 62% due to visible parts and transceivers. Of the avalanche victims, 55% were characterized as patients, and many of these suffered serious injuries. These statistics indicate that avalanche incidents are first and foremost medical emergencies, leading to the conclusion that medical personnel should be dispatched directly to the accident site without waiting or detouring for specialized resources for search operations.

Paper II: Descriptive statistics confirmed that the number of road related avalanche rescue incidents increased markedly in the study period. In the period 1996-2014, avalanches reaching public roads caused six fatal accidents, four personal injury accidents and fifteen close calls. Eleven out of 34 avalanche victims died (32.4%). Out of 135 incidents, 110 had no victims involved in the avalanches. From 1996 to 2014, no vehicles were completely covered by avalanche debris, and all onshore victims were located due to visible parts. In 62% of 45 analysed cases, in the period 2010-2014, the regional avalanche danger was at level 3: considerable.

In 78% of these rescue operations, rescuers were, to a varying degree, exposed in avalanche runout zones. The rescuers´ degrees of exposure correlated positively with deviations from a prescription for avalanche risk assessment and management. An exploratory factor analysis based on the analysis of deviations pointed to three latent factors: “Degree of avalanche risk awareness”, “Degree of commitment” and “Degree of application of risk reduction measures and mitigation”.

Qualitative and quantitative modelling with a Bayesian Belief Network showed a 63% probability of safe and efficient avalanche rescue performance. Overall, the analyses showed that rescue management in the alert phase, professional assessment of avalanche conditions, and continuous risk assessment are the most important risk influencing factors to control when aiming for an effective and safe rescue operation. In addition, actions to control undue haste and overcommitment and to enhance risk awareness will contribute to increased safety in this line of rescue work.

Papers III and IV: The reflections of 30 crew members from the Norwegian Helicopter Emergency Medical Service on the concept of overcommitment yielded a definition of overcommitment in the context of rescue activities; “Situations in which rescuers make themselves or others vulnerable by committing more than is feasible, desirable, expected, recommended, or compellingly necessary in the given scenario and thereby run the risk of personal injury or death”.

Air ambulance personnel recognize overcommitment in a variety of situations. They broaden the concept to include both regular, everyday actions and hazardous rescue attempts in extraordinary incidents. The causal factors and the definition of overcommitment could provide a basis for evaluation, learning and systems-based counteracting measures.

Air ambulance personnel pointed to sociological, cognitive, and organizational elements that may influence their degree of commitment in hazardous rescue situations. Their team-based approach to commitment moderation and operational uncertainty management could be adoptable by cooperating rescue organizations in the avalanche rescue service.

Paper V: The systemic safety analysis revealed that some groups of dispatchers and emergency personnel lack the recommended training and that they are not systematically equipped with basic avalanche safety equipment. The role of the police as a continuous controller at multiple managerial levels in the rescue service is also questionable. This points to assumptions that are failing, as regards compliance with safety requirements, the proficiency of important actors in the rescue service, the operationalization of the safety control structure and what is common avalanche rescue practice in Norway.

The most common explanations of recurrent unsafe control actions were inadequate control algorithms. Especially in road related avalanche incidents, this frequently leads to situations where first responding rescue units are exposed to considerable avalanche danger.

The safety control structure of the rescue service points to coordination risks. This is related to multiple controllers, overlapping and boundary areas of responsibility and complicated communication lines. There are challenges linked to: differing control algorithms between dispatch centres; rescue units which can be dispatched from several different dispatch centres; and an autonomous and uncoordinated response. This leads to a *"first come, first served"* situation, which is contradictory to the *"safety first"* attitude of the rescue service. The existing rescue system places few constraints on the first responding, and sometimes untrained, rescue units. The overall result indicates a lack of control of important processes in avalanche rescue operations.

The systemic safety analysis proved relevant and productive, as it directed the analyst's attention towards challenges related to the organization and management of rescue operations, rather than operator failures at the sharp end.

Conclusion: A synthesis of results from the various studies indicates that the Norwegian rescue service is vulnerable to common risk sources in rescue operations, affecting the safety of both rescuers and patients. The avalanche rescue system could benefit from a focus on the integrity of already established safety barriers. This implies an interorganizational effort to identify and reach common goals and system requirements.

This thesis may serve as input to discussions on risk acceptance levels in the rescue service, the applicability and validity of control algorithms in rescue management and how to adjust the degree of commitment in various rescue missions.

Samandrag

Innleiing: Snøskred skjer vanlegvis under vanskelege miljøforhold og forventa overlevingstid for skredofre er kort. Slike situasjonar krev ein omgåande respons frå redningsetatane, og det kan utfordre tryggleiken til både redningsmannskap og pasientar. Historisk sett, så har redningstenesta i Noreg opplevd få alvorlege ulykker, men uønskte hendingar der mannskap er farleg utsette i utløpsområder for skred er meir vanleg. Risikostyring i skredredningstenesta er mange-fasettert, og påverka av ein multi-organisatorisk struktur. Enkeltpersonar i dette sosio-tekniske systemet kan lett bli fanga mellom to imperativ; det å redde liv og det å halde seg sjølv i live. Målet for risikostyring er å halde redningsengasjementet i balanse. Dette prosjektet analyserte i kva grad den norske skredredningstenesta er godt nok balansert til å motstå ekstra påverknad frå vanlege risikofaktorar i redningsoperasjonar.

Mål: Hovudmålet med avhandlinga har vore å bidra til ny kunnskap om forhold som er viktige for risikostyring og yting i den norske skredredningstenesta.

Metodar: Det vart nytta ei fleirmetodisk tilnærming for å svare på forskingsspørsmåla. Det førte med seg fleire ulike forskingsaktivitetar i ein kombinasjon av både kvantitative og kvalitative metodar. Det fyrste

studiet var ei retrospektiv beskriving av norske snøskredhendingar og redningsaksjonar (Artikkel nr I). Ein omfattande studie som inneheldt statistikk over skredredningsaksjonar, fleirkasuistiske detaljanalysar, utforskande faktoranalyse og risikomodellering vart gjort for å få innsikt i redningstenesta si evne til å gjennomføra redningsaksjonar på ein trygg og effektiv måte (yting) (Artikkel nr II). 9 luftambulansemannskap på 5 basar deltok i fokusgruppeintervju i ein fenomenologisk studie for å utforske omgrepet over-engasjement i redningstenesta (Artikkel nr III and IV). Til sist deltok 6 ekspertar frå redningstenesta i ein system-teoretisk analyse av tryggleik i norske skredredningsaksjonar (Artikkel nr V).

Resultat: Studiane gav grunnlag for grunngjevne oppfatningar om tryggleik for både pasientar og redningsmannskap i norske skredredningsaksjonar.

Artikkel nr I: Norsk skredredningsstatistikk i perioden 2010-2017 synte at 75% av alle skredofre vart funne og gravne fram innan redningstenesta kom fram til skadestaden. Av dei resterande 25% som ikkje var funne av kameratar, så fann redningstenesta 62% av skredofra synlege på overflata, eller ved hjelp av sender-mottakar utstyr. 55% av skredofra vart karakterisert som pasientar, og mange var alvorleg skadde. Denne statistikken syner at skredulykker er fyrst og fremst medisinske naudsituasjonar. Det førte til ein konklusjon om at medisinsk personell bør sendast direkte til ulykkesstaden utan fyrst å måtte vente eller fly omvegar for å rykke ut saman med spesialiserte søkemannskap.

Artikkel nr II: Deskriptiv statistikk bekrefta at talet på skred-over-veg-aksjonar auka betydeleg i studieperioda. Frå 1996 til og med 2014 forårsaka snøskred som kryssa vegar 6 dødsulykker, 4 personskadeulykker og 15 nestenulykker. 11 av 34 skredofre omkom (32.4 %). 110 av 135 registrerte skredhendingar var utan skredofre. Frå 1996 til 2014 var det ingen køyretøy som var totalt overdekka av snø, og alle skredofre som ikkje vart ført ut i vatn vart funne synlege. 62% av skredhendingane i perioden 2010-2014 (n=45) gjekk føre seg under skredfaregrad 3, betydeleg. Dei andre hendingane skjedde under skredfaregrad 4 og 5.

I 78 % av desse redningsaksjonane var redningsmannskap, i varierande grad, eksponert i utløpsområder for snøskred. Grad av eksponering korrelerte positivt med registrerte avvik frå ein norm for skredrisikovurdering og -handtering. Den utforskande faktoranalysen, som var basert på den nemnde analysen av avvik, peika på 3 latente, samlande faktorar: "Grad av å vere medviten om skredrisiko", "Grad av engasjement" og "Grad av nytta risiko- og skadeavgrensande tiltak".

Kvalitativ og kvantitativ modellering med Bayesiansk nettverk synte at sannsynet for trygge og effektive redningsaksjonar ved skred-over-veg-hendingar var 63 %. Totalt sett synte analysane at leiinga av redningsaksjonane i varslingsfasa, profesjonell vurdering av skredtilhøve og kontinuerleg skredrisikovurdering er dei viktigaste risikopåverkande faktorane å kontrollere for å oppnå ein trygg og effektiv skredredningsaksjon. I tillegg, handlingar som skal førebyggje unødvendig hastverk og over-engasjement, og å gjera redningsmannskap meir medvitne om skredrisiko, vil bidra til auka tryggleik i denne form for redningsarbeid.

Artiklar nr III og IV: Refleksjonane til 30 mannskap frå ambulansehelikoptertenesta førte til ein definisjon av over-engasjement ved redningsaktivitetar; "Situasjonar der redningsmannskap gjer seg sjølv eller andre sårbar ved å engasjere seg meir enn det som er mogleg, ynskjeleg, forventa, anbefalt eller tvingande naudsynt i eit gjeve scenario, og som dermed risikerer personskade eller død".

Luftambulansemannskap kjenner att over-engasjement i fleire ulike situasjonar. Deira erfaringar har utvida konseptet til å femne om både kvardagslege oppdrag og hasardiøse redningsforsøk i ekstra-ordinære situasjonar. Årsaksfaktorane og definisjonen av over-engasjement kan fungere som eit utgangspunkt for evaluering, læring og system-baserte førebyggjande tiltak.

Informantane peika på sosiologiske, kognitive og organisatoriske element som kan verke inn på grad av engasjement i farlege redningssituasjonar. Deira lag-baserte tilnærming til justering av engasjement og operativ handtering av usikkerheit kan kanskje adopterast av samarbeidande organisasjonar i skredredningstenesta.

Artikkel V: Den system-teoretiske analysen av tryggleik i skredredningstenesta avslørte at nokre naudetatar manglar den opplæringa som dei er rådde til å ha ved redningsinnsats etter snøskredulykker. Dei er heller ikkje systematisk utstyrte med naudsynt utstyr for tryggleik ved skredulykker. Ein kan også setja spørsmålsteikn ved politiet sin rolle som kontrollør på fleire nivå i redningstenesta. Dette peikar på sviktande føresetnader om etterleving av reglar og anbefalingar som gjeld tryggleik, profesjonalitet hos viktige aktørarar i redningstenesta, operasjonaliseringa av den strukturen som er lagt til grunn for å kontrollere tryggleik og det som er vanleg praksis i skredredningstenesta i Noreg.

Dei vanlegast forklaringane til gjentekne usikre kontrollaktivitetar var utilstrekkelege kontrollalgoritmar. Særleg ved skred-over-veg-aksjonar førte dette til at dei redningsmannskapa som kom fyrst fram til ulykkesstaden ofte vart eksponert for betydeleg skredrisiko.

Strukturen for kontroll av tryggleik peikar også på risiko ved koordinering av redningsressursar. Dette er relatert til fleire kontrollørar ved ulike naudmeldingssentralar, overlappande og tilgrensande ansvarsområde og kompliserte kommunikasjonsliner. Det er utfordringar knyta til ulike kontollalgoritmar mellom naudmeldesentralar, redningsressursar som kan bli sendt ut frå fleire forskjellige naudmeldesentralar og ein redningsrespons som er autonom og ikkje koordinert med tanke på kven som skal komme fyrst fram til eit farleg område. Dette fører til ein "fyrst til mølla får fyrst male" situasjon, som er i motstrid til den “Tryggleik fyrst” haldninga som skal gjelde for redningstenesta. Det eksisterande redningssystemet legg få avgrensingar på dei, nokre gonger utrente, redningsressursane som kjem fyrst fram til skadestaden. Totalt sett, syner resultata ein manglande kontroll over viktige prosessar ved skredredningsaksjonar.

Den system-teoretiske framgangsmåten synte seg både relevant og produktiv. Den retta stadig merksemda mot utfordringar ved organisering og leiing av redningsaksjonar, heller enn mot feil hos redningsmannskap i den skarpe enden. Ei utfordring kan vere eit omfattande behov for dokumentasjon.

Konklusjon: Ein syntese av resultata frå dei ulike studiane indikerer at den norske skredredningstenesta er sårbar overfor vanlege risikokjelder ved redningsaksjonar. Det kan gå ut over tryggleiken for både pasientar og redningsmannskap. Skredredningssystemet kan med fordel fokusere meir på integriteten til allereie etablerte barrierar for tryggleik. Dette inneber tverr-organisatoriske aktivitetar for å identifisere og nå felles mål og funksjonskrav.

Denne avhandlinga kan tene som innspel til diskusjonar om kva for risikonivå ein kan akseptere i skredredningstenesta, om kor brukbare og gyldige algoritmane som blir brukte for å kontrollere tryggleik i redningstenesta er, og korleis ein kan tilpasse engasjementet i ulike redningsoppdrag.

Table of Contents

List of Figures

List of Tables

Part 2

List of papers

Appendices

Part 1

1 Introduction

The topic of this thesis is risk management in Norwegian avalanche rescue operations. Within this choice of term lies a recognition of the sometimes conflicting imperatives of rescue work: the patient`s right to an optimal rescue response (Helse og Omsorgsdepartementet, 2008; Saunes et al., 2010) versus the rescuers` own safety. Throughout this study, risk management is considered a balancing act (Aven, 2014, p. 161); is the avalanche rescue system correctly balanced to sustain the extra load of common risk influencing factors in rescue operations, like uncertainty, rescuer variability and changing environmental conditions?

This section will introduce the Norwegian avalanche rescue service and some important challenges related to its management of snow avalanche risk during rescue operations.

1.1 The Norwegian avalanche rescue service

1.1.1 Structure

The Norwegian rescue service is constituted by a joint effort of professional, volunteer and private organizations. Two Joint Rescue Coordination Centres (JRCC), in north- and south Norway, monitor, assist and instruct the Local Rescue Coordination Centres (LRCC), which are run by regional police headquarters. Calls of avalanche emergency can be made to either the LRCC (112), the Emergency Medical Coordination Centres (EMCC) (113), the Fire and Rescue Coordination Centres (FRCC) (110), or directly to the JRCC.

All four emergency coordination centres can initiate rescue operations and dispatch rescuers to incidents requiring an immediate rescue effort. The emergency call centres are obliged to notify their LRCC immediately in cases where the situation requires a coordinated effort defined as a rescue mission. Likewise, “The local Rescue Coordination Centre shall notify the Joint Rescue Coordination Centre without delay if the situation is perceived as a possible rescue mission” (Regjeringen, 2015). In Norway, a rescue mission is defined as: "Publicly organized immediate efforts by several partners to save people from death or injury due to an acute accident or hazards and which are not taken care of by specifically created bodies or by special measures” (Regjeringen, 2015).

The LRCCs are responsible for managing and coordinating onshore rescue operations within their own jurisdictional area. However, in emergency preparedness issues, the police have no instructional authority on other actors in the rescue service. As such, the rescue service is not directed by a single authority but relies on the competent management of every single rescue unit. Volunteer rescue resources are called out on demand, to assist in technical rescue management, avalanche risk assessment, searches of the avalanche debris, excavation, first aid treatment and evacuation of victims.

The Ministry of Justice and Public Security is the superior administrative office governing the rescue service, issuing decrees, regulations and instructions to influence emergency preparedness and operational abilities.

1.1.2 Systems and organizations

Nancy Leveson (2011, p. 63) states that systems theory was developed for systems exhibiting organized complexity – systems that are not easily available for analytic reduction and statistical methodology. Is the Norwegian avalanche rescue service a system and an organization with the characteristics of organized complexity?

The actors constituting the rescue service prepare for various types of emergencies and respond accordingly, following calls of distress. In all phases, though independent as organizations, they show interdependency in their activities, trying to achieve the common valued goal of rescue: saving lives (Regjeringen, 2015). In this sense, the rescue service is an operating entity "comprising discrete components which transform input to output for a purpose" (Hughes et al., 2015, p. 272).

Hughes et al. (2015) refer to six systems theory based criteria in their assessment of road safety strategies and their relation to systems theory, which in the context of avalanche rescue can be transformed to:

Key components: The rescue units constitute the unity of parts necessary to achieve the common goals of saving lives and operating safely. Although single components / rescue units sometimes act autonomously, fulfilling the task of a lifesaving action, they are always interacting with higher coordinating levels of command (Joint and Local Rescue Coordination Centres, EMCCs, FRCCs and Incident Commanders) and both pre-hospital and hospital-based medical resources. Without a successful chain of activities, the overall performance is reduced.

Relationships: All rescue units interact by command, common rescue techniques, and in communication and information.

Objective: The purpose of the rescue service is to "save people from death or bodily harm, resulting from acute accidents or hazardous situations", as formulated in the royal decree describing the organization of the rescue service (Justisdepartementet, 2015). In this context, the objective of safe operations must be added, as stated in The National Guidelines for Avalanche Rescue (NRR, 2012).

Interdependencies: The contribution and interaction of each rescue unit is described by law, regulations, guidelines and emergency preparedness plans. Interdependency underlines the importance of the united effort of all components to achieve the common goals.

Principles: The Norwegian rescue service is based on four principles (Justisdepartementet, 2015).

Firstly, the principle of *Samvirke*, which is a Norwegian word meaning a product of collaboration, cooperation, confidence, trust, common understanding and volunteerism (Aasland & Braut, 2018; Regjeringen, 2015, Chapters 1-4). *Samvirke* implies that all public agencies are obliged to contribute, with appropriate means, to a search and rescue operation. It also encourages a seamless integration of volunteer rescue resources. *Samvirke* was a major success factor in the rescue efforts following the terror attacks in Norway on 22nd July 2011, and this principle of cooperative organization was later formally approved as a principle of the Norwegian rescue service (Regjeringen, 2015). Lacking an adequate English expression, *Samvirke* is not being translated in this thesis.

It follows that all actors are responsible for effective cooperation, both in preparing for emergencies and during rescue operations. The principle of *integrated coordination structure* means that all operations, sea, land or air, are handled by the same organization. The principle of *responsibility* requires that the same agency that is responsible for handling daily tasks within a specific sector is also responsible for these activities during a rescue operation, irrespective of the extent and cause of the emergency. Lastly, the principle of *coordination* allocates this function to the JRCCs and the LRCCs.

As the rescue service is not one single organization, it is difficult to recognize principles in support of a specific avalanche rescue strategy, although The National Guidelines for Avalanche Rescue (NRR, 2012) fill the gap in outlining a common plan of action.

Theoretical basis: Norwegian avalanche rescue is based on best practice (Van Tilburg et al., 2017), interacting with both national and international research through the International Commission for Alpine Rescue (CISA-ICAR, 2019).

Based on these criteria, the Norwegian avalanche rescue service can be defined as a system. Considering the next question, whether the avalanche rescue service is an organization in the correct sense of the word, Hilde Brandshaug (2011) studied the performance of the Norwegian rescue service on the basis of organization theory and concluded that the Norwegian rescue service can be viewed as an *integrated project organization* – a hybrid of cooperation and project. This relates to the fact that the rescue service is constituted by several organizations, and that integrated units with inter-dependent tasks offer an optimal opportunity to solve complex challenges. Although a project normally has a defined beginning and end, the rescue service is running a series of projects – the projects emerge as a response to calls of distress. The repeated actions, and joint preparations and exercises, build longstanding relationships, enabling organizational learning. To achieve and uphold a high-performance level, in line with the ambitious objective of saving lives, and act cautiously, a holistic approach (systems view) is paramount. This requires intra- and inter-sectorial communication, information and trust.

1.1.3 Complexity of avalanche rescue operations

By royal decree, handbooks and guidelines (NRR, 2012; Regjeringen, 2015, 2018), the Norwegian rescue system is strictly hierarchically organized, with clearly defined roles and lines of command. The system assumes a centralized command over rescuers, who can act autonomously.

In practical terms, the rescue system represents public, voluntary and private organizations, different managerial levels, actors, functions and tasks. We also see that various elements of crisis management, emergency preparedness and preventive measures may be handled by different groups, agencies and individuals.

A rescue operation is managed by people with varying levels of knowledge, skills and experience, from a variety of organizations with differing safety culture and safety regulations. Rescue units cannot solely be differentiated by their professional status, since the systematic level of training varies within and between rescue resources. The level of training and experience amongst the responding rescuers in any given rescue operation is not known, thus introducing an element of uncertainty in rescue performance (Paper II). The workplace, “the plant” of operation, is unknown to the actors up until the time when they arrive at the accident site. The individual collaborators may be totally new to each other and ignorant of each other’s competence. It is much like playing a soccer match, every time with a new team, and every time at the “away” ground. Added to this is the urgency of the matter, always requiring a short response time and efficient rescue activities by whoever happens to be the first organized rescue responder.

Based on this multi-agency structure, the task-oriented goals, improvised and cooperative nature of activities, and complex interactions with multiple components in, sometimes unexpected, sequences (Perrow, 1984), the Norwegian avalanche rescue service is here considered an (integrated project-)organization, exhibiting organized complexity. Along with the previous conclusion that the rescue service is also a system, it follows that it is eligible for the application of systems theory and thinking.

1.1.4 Safety as an emergent property in avalanche rescue

Considering the structure and hierarchy of the avalanche rescue service, system safety – as a factor of pertinent avalanche risk assessment and management – is achieved only when all components interact actively through all phases of a rescue operation – it is an emergent property arising from system component interaction (Leveson, 2011, p. 67) (Papers II and V).

From a chronological and hierarchical perspective, rescuers` exposure to avalanche risk may result from a lack of coordination and control activities at higher levels, as “Safety then can be viewed as a control problem” (Leveson, 2011, p. 67). In this thesis, it is questioned whether valid safety constraints are in place and known to the managerial levels in the various organizations involved in avalanche rescue operations. If not, can this be linked to deficiencies in the common process of identifying basic goals, hazards and system requirements (Leveson, 2011, p. 203) (Paper V)?

Safety objectives, prioritized by leaders at all levels, are amongst important pillars supporting high reliability organizations (Aven et al., 2004; Weick et al., 2008). Leveson, however, claims that it is not prioritizing the safety goals that is a major problem, “but making difficult tradeoffs and decisions about how much risk is acceptable and even how to measure the risk” (Leveson et al., 2009, p. 240). This points back to the dilemmas involved in risk management, as rescuers regularly experience a goal conflict between rescue efficiency and rescuer safety, in which “Declining a rescue attempt must be a socially acceptable and respectable option where the risks are considered genuinely intolerable” (Ash & Smallman, 2010, p. 47) (Papers III and IV).

The hierarchical structure of the rescue service seems to invite a systems thinking approach to safety. In this context, a closer examination of the safety control structure of the avalanche rescue service (Paper V) might act as a preparation for further evaluation of specific rescue operations. It might also serve as a basis for defining suitable risk indicators for land-based winter rescue in Norway (Section 4.6.1). A systems view on avalanche rescue performance is necessary when looking for “ways to enhance the ability of systems to succeed under varying conditions” (Hollnagel, 2011, p. 1).

1.1.5 Risk and avalanche rescue in Norway

In Norway, avalanche rescue operations have increased in number over the last 20 years (Papers I and II) and represent major challenges for the emergency response organizations. The challenges are mainly linked to performance, i.e. how to conduct efficient and safe rescue operations in challenging environmental conditions. The main areas of operation are in uncontrolled, free mountain terrain or along public roads which run through narrow valleys, exposing the rescuers to considerable danger of being hit by neighbouring, secondary avalanches (Glassett & Techel, 2014; Lunde & Kristensen, 2013).

Luckily, no Norwegian avalanche rescuers have come to harm since six local rescuers were killed in 1971, in Hjørundfjord. Historically, no fatalities amongst avalanche rescuers in more than 45 years looks a flattering result for the Norwegian rescue service. Statistically, however, it may look less flattering. Based on data from the Norwegian Avalanche Rescue Database (NARDB) (Papers I and II), in the period 1996-2017, the average duration of Norwegian avalanche rescue operations was 2.7 hrs; the average number of rescuers per operation was 15.6; and the average number of rescue operations per year was 34. Extrapolating this over a period of 50 years, this adds up to 72,000 rescuer hours and, as previously stated, 6 fatalities. The number of fatalities per million person rescue work hours is then (Rausand & Utne, 2009, p. 56): 6 / 0.072 = 83.3. By comparison, the Helicopter Safety Study 2 (Hokstad et al., 1999), estimating risk for North Sea helicopter transport 1990-1998, found a fatality rate of 2.3 per million person flight hours. So, despite no fatal accidents in the last 50 years, we see that the fatality rate per work hour is unreasonably high, compared to other seemingly risky and necessary activities in society.

This is all a question of perspective and scale. Firstly, we could see these numbers in the perspective of major accident risk, i.e. highly infrequent accidents with multiple casualties. Low annual accident rates can be quite deceptive, leading organizations towards complacency and habitual high risk practice (Leveson, 2011; Rasmussen, 1997), since the individual rescue units "never" experience accidents. Infrequent accidents are difficult to approach with statistical studies, especially as regards uncertainty in the various parameters that could indicate a shift of risk towards unacceptable limits. Monitoring major accident risk requires vigilance and "sensitivity to operations" (Weick et al., 2008, p. 45). It is therefore necessary to also develop and monitor other risk indicators than fatality rates (Section 4.6.1).

Secondly, since these rescue operations are handled by many different teams and individuals, not by one identifiable, large company, and many years may pass in between accidents, the fatality rate is not very useful as an operational indicator of safe practice (Hopkins, 2009). In the oil and gas industry, loss of containment (e.g. gas leakages) is used as an indicator of major accident risk. In this line of work, we may consider incidents where rescuers are exposed in runout zones during high avalanche risk as "loss of containment". These incidents are more frequent (Paper II) and countable on a small scale, thus enabling a monitoring of accident risk at all levels. "If serious failures are rare, one means to get more data points for learning is to broaden the number and variety of failures that are given close attention" (Weick et al., 2008, p. 39).

The accident in Drümännler, Switzerland, in 2010 (Etter, 2010) is one of the latest documented major accidents in avalanche rescue. Seven people, including the patient, companion rescuers and an air ambulance doctor, died in a secondary avalanche during the initial stage of the operation. Overall, in Italy, in the period 1985-2009, 6% of avalanche accidents involving "mountain professionals" happened during rescue operations (Valt et al., 2009). These accidents point to the challenges linked to avalanche risk assessments and how to avoid dangerous acts in spatially variable and dangerous conditions.

Leading up to this study, I was not at ease with the historically low fatality rate of Norwegian avalanche rescuers, since observational studies (Lunde & Kristensen, 2013) and anecdotal evidence indicated a high frequency of undesirable incidents. On one occasion, near the town of Sunndalsøra, Norway, on 15th March 2010, 14-15 rescuers at work had to run to escape from a naturally released secondary avalanche (Fange, 2010). Avoiding accidents is an expression of adequate performance in rescue operations, and efficient and safe rescue operations are a significant societal safety factor. Therefore, an avalanche accident involving rescuers may take the dimensions of a national disaster and will attract great public interest; cf. the Vassdalen accident in 1986, in which 16 Norwegian soldiers died (Lied, 1988; NOU, 1986, p. 20)

1.1.6 Norwegian avalanche rescue statistics

In the 22-year period from 1996-2017, the Norwegian Joint Rescue Coordination Centres registered 720 avalanche incidents, with an annual mean of 33 ± 7. In 360 of these incidents, rescuers were called out and searched in avalanches without any involved victims. Only 35% of the incidents were avalanche accidents requiring a rescue response. In the remaining 15% of the incidents, rescuers were dispatched but not activated on site. A total of 568 avalanche victims were recorded in 279 accidents, and 313 of these victims were counted as patients, of whom 120 died.

1.2 Thesis limitations

The risk management perspective in this thesis is limited to snow avalanche risk, i.e. the hazards related to travel and rescue activities in avalanche terrain, how this is assessed and managed by the involved parties, at all managerial levels, and what consequences this might have for the safety of rescuers and patients. This means that all other types of hazards, e.g. road traffic and snowmobile accidents, are not a part of the considerations and analyses in this project. However, transportation hazards as a consequence of operative decision-making are included in Papers III and IV.

As regards patient safety, the selected risk management perspective also includes dispatch and prioritization of rescue resources in all types of avalanche rescue operations and the consequences these rescue activities might have for the patients` prognosis and well-being.

1.3 Thesis aims

The main objective of this PhD project was to contribute to new knowledge on factors that are important for risk management and performance in the Norwegian avalanche rescue service. Knowledge in this respect is defined as propositional knowledge, expressed as “justified beliefs” and generated in reliable scientific processes (Aven, 2014, pp. 64-65). Important issues in this context are the concept of overcommitment and long-term monitoring of accident risk.

Detailed aims were:

Paper I: to present a basis for evaluation and necessary adjustments in the dispatch, prioritization and management of Norwegian avalanche rescue operations.

Paper II: to present characteristics of Norwegian road related avalanche incidents and rescue operations; the rescuers’ degree of exposure to avalanche risk and their risk assessment and management activities during these rescue operations; and, finally, a Bayesian network model of the overall performance of the Norwegian avalanche rescue service in road related avalanche rescue operations.

Paper III: to present how overcommitment is described and understood by Norwegian Helicopter Emergency Medical Service personnel, as a uniform concept in rescue operations.

Paper IV: to present how overcommitment is identified and managed by the frequent first rescue responders in the Norwegian Helicopter Emergency Medical Service.

Paper V: to present a systems theoretic process analysis (STPA) of the Norwegian avalanche rescue service and a subsequent evaluation of its applicability in the context of socio-technical, multi-organizational activities like avalanche rescue operations.

1.4 Thesis structure

The thesis comprises two chapters. The first chapter, containing six sections, is a cross-paper elaboration of the rationale behind the various studies, the theories on which the research perspective is based and a presentation and discussion of methods, results and main findings. The conclusion offers a short summary of important results, suggestions for follow-up studies and important improvements in avalanche rescue practice. The last chapter contains copies of Papers I-V.

2 Theory

Snow avalanche rescue is a complex process, incorporating knowledge from a wide range of research disciplines. The following is a presentation of selected theory related to the focus points of this thesis: risk and management of risk in snow avalanche rescue operations, human factors in rescue work and long-term monitoring of accident risk. In addition, each of the Papers I-V contains theoretical contributions which are specifically related to the research questions of the various studies.

2.1 *Risk, uncertainty and probability*

Recognizing risk and constructing risk images on which to base decisions about safety are continuous and critical activities for rescuers. The activities may be structured risk analyses or, more commonly, simple observations and discussions during stressful moments of rescue response. In these situations, rescuers are acting as both risk analysts and decision makers (Braut et al., 2012), and the decisions may affect single rescuers, rescue units and the avalanche victims. The activities of rescue work seldom cause externalities, although there is a chance that rescuers trigger avalanches that could hit other people in the area. Of course, air rescue activities always carry the possibility of causing harm to third parties, but this issue is not included in the scope of this thesis.

The combination of the consequences (C) of the rescuers` decisions to respond to (or not respond to) an avalanche accident (A) and the associated uncertainties (U) (Aven, 2014, pp. 33 and 40) constitutes the framework for understanding and describing risk in this thesis. The uncertainties are linked to the rescue activities in the response phase, environmental conditions like avalanche activity, the avalanche incident, the patient`s condition or the consequences thereof. The future events or consequences are unknown. Even the most extensive work to reduce uncertainty about avalanche release will not bring us to a state of omniscience – an ability to foresee everything (Njå et al., 2017). It is simply not possible, even during high avalanche risk conditions, to predict with certainty that an avalanche in a known path is going to descend or not (Schweizer, 2008), despite extensive historical data from the area. Only in hindsight may it be possible to see the outcome, e.g. avalanche activity in the area of operations.

A fundamental lack of knowledge as a basis for accurate predictions points to "scientific uncertainty", i.e. "We are unable to reconstruct the causal connections with a high degree of confidence and reliability" (Aven & Renn, 2010, p. 73). It can be debated whether this scientific uncertainty is "Small" or "Moderate" (Aven, 2014, p. 162). A terrain-based assessment will tell us exactly where the avalanche may descend, and snow avalanche research has made important contributions to our knowledge of snow avalanche fracture mechanics. However, our present understanding of the interplay between variable snowpack characteristics and the influence of terrain and weather factors does not allow a high degree of accuracy in predicting sensitivity to triggering, the time of avalanche release and avalanche size (volume, exact runout length and destructive force) (Kronholm et al., 2002; McClung & Schaerer, 2006; Schweizer, 2008). If having to work beneath a huge avalanche release zone, uncertainty also relates to our confidence in the models we apply to predict avalanche release (Aven & Renn, 2010, p. 73). Most likely, the level of confidence in risk analysis models will vary between individual rescuers, giving rise to disharmony in dynamic, real-time risk assessments and risk acceptance levels (Ash & Smallman, 2008; Penney, 2019, pp. 6-8).

Steven G. Vick (2002, pp. 254-256) points to the importance of acknowledging uncertainty as a first step in admitting to the reality that total knowledge is elusive. If reality calls for caution, a cautionary strategy to risk management is recommended (Aven, 2014). The ill-defined remaining uncertainty forces the rescue service "to place more emphasis on vulnerability and resilience assessment (are we able to cope with the surprises?), inclusion of less uncertain alternatives in the assessment, and using more refined and comprehensive methods for characterizing unknowns and uncertainties (for example by selecting experiential knowledge from people who have experience with the risk)" (Aven & Renn, 2010, p. 74).

Obviously, the background knowledge (K) and transparency regarding its strength and relevance is crucial for the quality and trustworthiness of the judgements of mission risk. In emergency preparedness planning, it is reasonable to expect a certain level of documentation, e.g. as suggested by Aven (2008, 2014) and Berner & Flage (2017). In dynamic emergency response situations, the strength of knowledge supporting the risk assessments must be ensured by the alert and dispatch routines, i.e. only competent personnel, at all managerial levels, should be engaged in rescue operations (NRR, 2012).

When referring to the vulnerability of avalanche rescuers, patients, companion rescuers and bystanders, the sources of risk (RS) considered in this project are limited to avalanches reaching the areas of operation, flawed rescue management or inadequate avalanche risk assessment. In the case of an avalanche hitting rescuers on the ground, inside or outside vehicles (C,U,K | RS), we can make a judgement about the consequences, based on statistics; the overall mortality rate in Norwegian avalanche accidents is 0.22-0.32 (Papers I and II) and internationally around 0.40-0.50 for those totally buried in the avalanche debris (Haegeli et al., 2011; Hohlrieder et al., 2007; Lunde & Kristensen, 2011; Techel & Zweifel, 2013; Tschirky et al., 2000).

It is clear from the mentioned studies that consequences can be reduced by using avalanche safety equipment, but survival cannot be guaranteed. As regards patients, rescuers who arrive late or who abstain from a rescue attempt (RS) will worsen their prognosis (C, U, K | RS). Safety equipment, risk awareness and mindful dispatch of rescue resources are examples of safeguards used to reduce the effect of various hazards on our activities, objects or objectives. The logic is that the overall risk can be reduced by applying relevant safeguards (Kaplan & Garrick, 1981, p. 12).

Braut et al. (2012) recommend the concept of risk images to reflect the decision makers' belief in possible outcomes of different alternative decisions. The risk image needs to reflect all dimensions of risk (A,C,U,K) (Aven, 2008), as well as our predictions of events and consequences, e.g. avalanche activity and the consequences for rescuers and patients.

2.1.1 Measures of uncertainty – Probability

In any situation dominated by uncertainty, the answer to most questions will include the words "probably" or "as far as I know". In the context of risk, not knowing is dangerous and, as a substitute for certainty, we can grade and describe uncertainty, e.g. by using the concept of probability. By ascribing values between zero and one, we can communicate our thoughts as to whether a specific event will happen or not – we offer "a measure of uncertainty" (Aven, 2012, p. 39). We can simulate an event by introducing probability models, but they presume stability, which in the real world is difficult to attain. There will be variations in both the populations and situations studied, with respect to relevant factors and the assigned parameters. The way you choose to analyse and present a phenomenon will, of course, have an impact on both the results and the degree to which the results are meaningful to the decision makers. In that respect, transparency is important in all phases of the risk analysis.

Against this background, we see different views on probability, starting with the classical approach, dating back to de Laplace in 1812, requiring a finite number of equally likely outcomes – a situation which is hardly attainable in real situations of avalanche risk. The frequentist interpretation, which is usually denoted "the law of large numbers", requires that the events are repeated an infinite number of times, and is often represented by a normal distribution. It can be argued that the inherent variability of snow avalanche release and runout lengths forces the risk analyst to consider this natural hazard a unique event, and in that case the frequentist approach would not make sense. It is clearly not possible to repeat the avalanche an infinite number of times, and the "experiment" is not repeatable under the exact same conditions (Schweizer, 2008; Watson, 1994). Contrasting with this approach is the Bayesian, subjective approach, in which probability values are assigned "with reference to an uncertainty standard" (Aven, 2012, p. 194; 2014, p. 221), i.e. the uncertainty about an event is compared to the likelihood of drawing a specific ball from an urn containing ten balls. The assignment itself is based on available knowledge, historical data and experience. In this approach, the basis for selecting specific probability values can be questioned, whereas the values themselves are the risk analyst`s expressions of uncertainty about the variables in question. For further discussions on this approach, please see Paper II.

2.2 Predictability of avalanches

2.2.1 Avalanche release – Stability evaluation

An avalanche release zone is the part of the terrain with a slope inclination > 25^{o} (Lied & Kristensen, 2003; McClung & Schaerer, 2006), and the runout zone is the part of the avalanche path where the debris comes to rest (α maximum). The avalanche track is the area between the release and the runout zones and follows natural terrain features.

One of the main puzzles for snow scientists to solve has been that of avalanche release mechanisms, which cannot be fully explained solely by analysing forces acting on objects resting on inclined planes, although "Simple failure criteria of the Coulomb type were adequate for treating planar slip" (Mellor, 1976, p. 252). Obviously, it is reasonable to conclude that snowpack structures are subjected to greater shear forces on steeper inclines, but numerous observations confirm that avalanches can also be triggered from flat ground, contraindicative of shear strength as the limiting factor for avalanche release (Johnson et al., 2004). Although the release of a snow slab results in a progressive shear fracture along the weak layer, isolated calculations of stress and strain in the snowpack show that it is, in fact, not possible to arrive at the high stresses necessary for a homogenous, isotropic snowpack to fracture (Lied & Kristensen, 2003). The answer to this contradiction was originally based on the work of Alan Arnold Griffith (1893-1963), (Griffith, 1920), who, in 1920, concluded that an inherent weakness in a brittle material is sufficient for fracture. Much later, from 2000 onwards, the most recent add-ons to Griffith`s theory now show that an initial downwards collapse of a weak layer is followed by a propagating fracture. Several important measurements and tests by Johnson et al. (2004) and van Herwijnen and Jamieson (2007) led up to a breakthrough, until, finally, two studies by Heierli et al. (2011; 2008) demonstrated that "A small number of factors increases the risk of triggering fracture: the intensity and the direction of the skier load, the depth of the weak layer, the stiffness and penetrability of the slab, the fracture energy of the weak layer, and the size of flaws". None of these factors is easily observed and controlled by humans. They also concluded that slabs are as equally easy to trigger on gentle as on steep slopes. Earlier, several studies by Kronholm et al (2002), Schweizer et al 2003) and Schweizer & Kronholm 2007 showed considerable spatial variation in both snowpack structure and stability, which explains why important factors for snow avalanche release are not easily observed and controlled.

The activity of naturally released avalanches is indicative of the density and distribution of triggering spots (Schweizer et al., 2018) and supports judgements of snowpack stability.

Emma Kate Howley (2007) developed classification trees in her study of wind drift and precipitation levels as predictors of natural release of snow avalanches in Grasdalen, Norway. Offering no exact critical values for avalanche release, she summarized that her thesis "highlights the complicated relationship between preceding weather conditions and avalanche occurrence indicating the vast array of factors to be considered for avalanche prediction". Howley referenced a study by Kronholm et al. (2006), in which they showed a misclassification of all avalanche days to be 15%. In their introduction, they state that a spatio-temporal prediction of avalanche release is impossible, concluding, however, on page 10: "Based on a set of simple meteorological parameters it can reasonably well be predicted whether a day will have avalanches or not".

The implications of these findings are that neither regional avalanche forecasts nor isolated local stability evaluations can offer an adequate degree of certainty to decisions about safe crossing of avalanche release zones. For rescuers, this means that avalanche release zones with dry, layered snow must be considered as "no go" areas. This is reflected in the risk analysis model presented in the National Guidelines for Avalanche Rescue (Lied & Kristensen, 2003, p. 119; NRR, 2012).

2.2.2 Avalanche size – Runout length

The runout length of avalanches is another critical variable in avalanche emergencies. The runout is dependent on both terrain features and snow characteristics (McClung & Schaerer, 2006). The Norwegian Geotechnical Institute (NGI) (Lied & Kristensen, 2003, p. 82) has observed maximum runout lengths equal to an angle of sight of 18^{o} from the end of the debris to the top of the release zone. The maximum runout length (α maximum) can be calculated using various models, and the statistical-topographical alpha-beta model developed by NGI is prevalent in avalanche risk assessments in Norway (Lied & Kristensen, 2003, p. 81).

Many Norwegian road sections cross known avalanche paths, also as high upslope as in the release zones (Kristensen et al., 2008). This implies that even small avalanches may reach the roads, and the annual frequency of avalanche blocked roads is relatively high (Bjordal & Larsen, 2009; Busterud, 2016). The most frequent avalanche danger level during which public roads are blocked by avalanches is level 3 – considerable (Orset et al., 2017). This also corresponds to the most frequently observed danger level during Norwegian road related avalanche rescue operations in the period 2010-2014 (Paper II).

Naturally, rescuers responding to road related avalanches travel along these roads, often in periods of widespread avalanching (Paper II). The European avalanche danger scale (EAWS, 2016) describes an increasing frequency of naturally released avalanches with the higher danger levels 3-5. This is supported by several studies (Schweizer et al., 2003; Techel & Schweizer, 2017), even though the use of this five-step model allows considerable inter-rater and inter-regional variability (Schweizer et al., 2018). The size of avalanches did not correlate clearly with danger level, which led the authors to suggest a revision of definitions used in the model. The determination of avalanche size is based on runout length, damage potential and volume (EAWS, 2016). These input parameters to avalanche forecasting are usually estimated from a distance, not measured, so inter-rater variability is not uncommon (Moner et al., 2013).

The challenge for rescuers is to predict the possible size (runout length) of an avalanche in a given path, based on an estimation of snow depth in the release zone and available snow for entrainment along the avalanche track. For engineering purposes, McClung and Schaerer (2006, p. 136) advocate a combination of historical data and observations of avalanche debris and damage to vegetation and infrastructure to determine runout lengths. They further state that the use of avalanche dynamics models implies risky assumptions. The statistical-topographic approach is also criticized by the authors for weaknesses linked to precision and applicability across different mountain ranges. These methodological challenges underline the uncertainty involved in predictions of avalanche runout distances: uncertainties that may pose very practical and dangerous consequences for rescuers in time-critical situations.

Aggregated quantitative data is, no doubt, useful input to risk analyses but offers little guidance in future unique, fateful moments of rescue operations (Aven, 2012, pp. 7-11; Braut et al., 2012). In cases where rescuers travel on the ground in avalanche terrain, they need to assess whether avalanches can release and reach their position. Commonly used roads and routes can be predefined and mapped in detail, also with regard to return periods for specific avalanche paths, i.e. the frequency with which avalanches reach a specific position. Naturally, short and small avalanches have higher frequencies than long and large avalanches (Lied & Kristensen, 2003; McClung & Schaerer, 2006). This encounter probability can be given in qualitative or quantitative terms, which is a matter of debate in avalanche forecasting programmes (Kristensen, 2016).

The European Danger Scale (EAWS, 2016) offers a five-degree qualitative description of avalanche danger, and regional forecasts with the predicted danger levels are usually assigned to areas of 100 km^2 or more. These forecasts are not intended for local-scale decisions about avalanche risk. To inform decision makers in questions regarding closures of road and railway sections, evacuation of production sites and protection of infrastructure, object-specific forecasting programmes are established. These forecasts are issued for shorter periods of time, normally 24 hours, and the encounter probability is often rank ordered as “Low”, “Medium” and “High”. Vick (2002, p. 258) argues that qualitative approaches introduce more ambiguity and that they conveniently sidestep the efforts of quantification. On the other hand, a numerical assignment of probability, as a value between 0 and 1, was considered undesirable by experienced forecasters at the Norwegian Geotechnical Institute, since “This gives an impression of an unrealistic high precision” (Kristensen, 2016, p. 3).

In rescue operations, informal and ad hoc “local forecasting” is conducted by the responding rescuers, as they try to assess avalanche safety along their selected routes. The rescuers may find decision support in applying various models for avalanche risk analysis; then they must base their input data on assumptions and uncertain information about local snowpack and avalanche path characteristics. “A major fundamental physical uncertainty in avalanche forecasting resides in the usually unknown temporal and spatial variations of instability in the snow cover, including their links to terrain” (McClung & Schaerer, 2006, p. 148). The output from the various models invariably contains an undefinable portion of uncertainty, sometimes termed “residual risk”. In practical terms, “residual risk” means “life threatening danger”.

Pre-rescue calculations of individual risk to road users travelling specific avalanche-prone road sections may inform decision makers about the overall risk level in the area. Such calculations are demonstrated by Kristensen et al. (2003), showing example probability values of 0.0001 and 0.15 for moving and stationary cars to be hit by secondary avalanches along specific road sections. Expected values, however, do not account for outliers and will generally not apply to the situation at hand. Aven (2014, p. 25) states that “The use of expected values in risk management can seriously misguide decision-makers in practice”. In this context of local forecasting, the calculations involved are also questionable, as spatially relevant real-time input data is generally scarce (Aven, 2008; Kristensen, 2016).

2.3 *Risk management in integrated project organizations*

A characteristic feature of avalanche rescue operations is that the victims are in a danger zone with spatio-temporal variability in avalanche risk. With reference to the previous sections, we may conclude that accurate predictions of avalanche activity are hardly attainable, so avalanche risk to rescuers needs to be regulated by their degree of presence in the danger zones. To some extent, risk can be reduced by removing the snow in the release zones, e.g. by blasting. This is, of course, not a preferred strategy in the initial stages of rescue operations, as it may endanger avalanche victims. Management of risk in these circumstances needs to be continuous and mindful, as tasks change along with changes in the environmental conditions and the situation (Tissington & Flin, 2005). To stay safe while in avalanche terrain is therefore, to a large extent, based on individual knowledge, skills and attitudes.

Risk management per se is a managerially structured approach to ensure that rescuers avoid harm’s way in their efforts to save lives. It includes all activities to achieve, maintain and improve on a predefined level of safety (Aven et al., 2004). Safety “is an internal construct” open to individual interpretation (Vick, 2002, p. 257), so exact safety levels are difficult to specify, measure and communicate in objective terms. Safety is also a multifaceted concept relating to our physical environment, as well as human and social factors, encouraging us to believe that individual and organizational initiatives may influence our feeling of safety and our susceptibility to accidents (Aven et al., 2004). This perspective is reflected in the framework for accident data collection and analysis – “Occupational Accident Research Unit” (OARU) (Kjellén, 2000; Kjellén & Hovden, 1993). An accident is considered an element in a process, preceded by deviations from norms and requirements (Figure 1). Deviations demonstrate a lack of control, eventually leading to a total loss of control – and accidents (Leveson, 2011; Rasmussen, 1997).

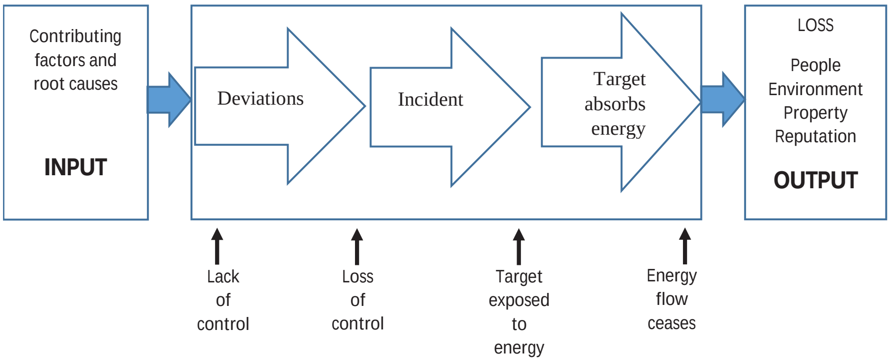

Figure 1. OARU. The *"Occupational Accident Research Unit"* model for accident data collection and analysis (Kjellén, 2000; Kjellén & Hovden, 1993).

We have previously concluded that the avalanche rescue service is an *integrated project organization* (Brandshaug, 2011), and we observe that rescue activities, including risk management and accident prevention activities, are carried out as a temporary collaboration of cooperating organizations. Since the rescue service is not one single organization, there is no senior management to establish and maintain common health, safety and environmental systems. In the rescue service, the "safety organization" arises spontaneously when rescuers meet at the accident site, with the challenges this entails for mission assessment and completion. Most important in this context are differences in safety culture, variable competence and differences in risk acceptance levels in the various organizations – and between individual rescuers. In each rescue operation, there will be a challenge related to "the collective understanding of what is dangerous and how to contribute to reducing the dangers" (Aven et al., 2004, p. 34).

An overall risk acceptance level has not been set for the Norwegian rescue service, and words like "safety", "risk" or "risk management" are not mentioned at all in an authoritative document like the "Plan of organization for the Norwegian rescue service" (Regjeringen, 2015). It does, however, outline the structure, hierarchy and responsibilities of the rescue service, including the JCRCCs` auditing of LRCCs. Safety and risk management is described only in general terms in the “Handbook for the rescue service” (Regjeringen, 2018). The focus is on the individual rescuer`s own responsibility to “act as safely as possible. Beyond that, the management of each agency / organization must take a special responsibility” (Regjeringen, 2018, p. 71). One may assume that this approximates the principle that the risk should be kept *as low as reasonably practicable* (ALARP) (HSE, 2018), without specifying upper and lower limits for a tolerable range. None of these documents specifies overarching roles in risk management, apart from the tactical responsibility of the Incident Commander (from the Police) during rescue operations. As regards professional emergency response organizations, it is reasonable to expect that the safety regulations laid down in the Norwegian “Working Environment Act” (Fougner & Holo, 2006; Regjeringen, 2005) are also applicable and mandatory in avalanche rescue operations.

“The National Guidelines for Avalanche Rescue” (NRR, 2012) offer general recommendations on safety measures, stating that “Search and rescue activities are to be conducted with as low risk as possible” and that risk assessments are to be conducted “on all levels, prior to and during rescue operations…in accordance with the methodology of the individual organizations”.

These documents confirm the socio-technical structure of the rescue service, also acknowledging, however, that the participating organizations are acting on their own premises. Both vertically and horizontally, the individual organizations and management levels will influence the overall ability of the rescue service to conduct safe and efficient rescue operations (Rasmussen, 1997).

Safe operations require the avoidance of critical errors, and an accumulation of errors over time may proceed gradually and unnoticed until total failure (Dekker & Pruchnicki, 2014; Turner & Pidgeon, 1997).

However, measuring the safety of an organization by counting errors and deviations from norms is controversial (Leveson, 2011; Rasmussen, 1997; Reason, 1997). Given the complexity of avalanche rescue operations, the rescuers' ability to improvise and deviate from guidelines will be important to reflect the changing demands and environmental conditions. In this perspective, deviations may then be considered necessary operational optimization – not human error (Reason et al., 1998), and operations succeed because operators adapt to the demands of current situations (Hollnagel et al., 2015). "It all depends on the local conditions and the adequacy of the procedures" (Reason, 1997, p. 73).

Siri Wiig studied risk and error management processes across organizational interfaces in the Norwegian health services (2008) and concluded that "Different system levels are dependent on each other in the process of error prevention" (Wiig & Aase, 2007, p. 10). In a systems view, errors are indications of underlying organizational problems, and a collective, interorganizational capacity to avoid errors is required to avoid accidents.

Leveson and Stephanopoulos call for a "system-theoretic control-inspired" perspective in risk management. In this perspective, safe operation "is a constraint on how the mission…can be achieved, where by constraint we imply limitations on the behavioural degree of freedom of the system components" (2014, pp. 1 and 6). This approach dates back to Jens Rasmussen and his hierarchical safety control model of risk management (1997). In his view, risk management is a control task, and control can be enforced in many ways on different levels in the management structure. Rule-compliance is in line with Nancy Leveson`s view that safety is a control problem (2011), and the objective of exerting control is to avoid habitual operation on the margin of safe practice. Leveson presents the assumption that "Operator behavior is a product of the environment in which it occurs" (2011, p. 47), thus focussing on the mechanisms that shape human behaviour rather than on operator errors.

Andrew Hopkins (2011, p. 5) debates rule-compliance and risk management as two complementary approaches. He states that "Decision makers need rules, not numerical risk acceptance criteria, to guide their decisions". For the sharp-end decision makers, rules may act as guidance to draw a line between acceptable and non-acceptable risk taking, termed "the line in the sand" by Jan Hayes (2012). From this perspective, rules are considered safety barriers, and the integrity of such barriers is considered paramount to safe operations. In her study on hazardous industries, managers of operations observed the status of barriers and applied professional judgement to establish self-imposed limits for final decisions on how to proceed in non-normal situations. In operational decision-making, less attention was paid to (uncertain) results from risk assessments and more to "How best to proceed", comparing it to a job safety analysis.

Rule- and constraint-based risk management is rooted in the cautious/precautious risk management strategy (Aven, 2014), accounting for uncertainties in our understanding of important phenomena and surprises in operations. In a robust approach, the focus will be on barriers to resist surprises, in recognition of the inherent uncertainties in risk assessments. In view of the challenges linked to climate change and natural hazards (Bjordal & Larsen, 2009), "Robustness in this context…should also cover the ability to cater for unknown requirements that may arise at a later stage of the field life cycle" (Vinnem, 2014, p. 369).

2.4 Human factors in avalanche rescue

A fundamental knowledge about snow avalanche physics is necessary but not enough to stay safe in avalanche terrain. So, there is more to sound decision-making than being knowledgeable and skilled, as demonstrated by the incidence rates of professionals in avalanche accidents (Horgen, 2017; Johnson et al., 2016). In Switzerland, in a five-year period preceding 2006, 18% of victims were under the supervision of mountain guides (Walter & Brügger, 2012). A common denominator in avalanche accidents is that the victims have overlooked or ignored danger signs, or they have not taken adequate precautions in obviously dangerous conditions (Atkins, 2000; Vanpoulle et al., 2017). In spite of detailed information on snow, weather and terrain factors in avalanche bulletins, most avalanche accidents take place during danger level 2 and 3 conditions (EAWS, 2016; Greene et al., 2006; Techel & Zweifel, 2013). On recognition of this context, the role of human factors in avalanche accidents has gradually become an important part of avalanche training and accident analysis (Adams, 2004; Atkins, 2000; McCammon, 2002, 2004, 2009).

Many sad accidents in aviation are also linked to human factors (Braithwaite, 1999), with “Controlled Flight Into or Toward Terrain” being a most disturbing and quite common category (Boeing, 2018; Winn et al., 2012). Accidents when flying in darkness and adverse weather conditions are typical, and “Pilot decision making” and “External environment awareness” are frequent “Standard Problem Statements” (Blumen, 2012; Winn et al., 2012, p. 80). In aviation as in avalanche accidents, lack of experience does not totally reflect the important array of possible explanations.

To reduce human errors as a cause of aviation accidents and to improve pilot performance, Crew Resource Management (CRM) (Cooper, 1980; Helmreich et al., 1999) was introduced, and the CRM training programmes has achieved international recognition and dissemination.

In the original workshop report by Cooper et al. (1980, p. 7), a list of frequently observed problems was presented:

- Preoccupation with minor mechanical problems
- Inadequate leadership
- Failure to delegate tasks and assign responsibilities
- Failure to set priorities
- Inadequate monitoring
- Failure to utilize available data
- Failure to communicate intent and plans

Later developments of this approach now include topics related to cognitive errors, social psychology, teamwork, behavioural and communication skills, safety culture and safety climate (Flin et al., 2008; Salas et al., 2000). Although its efficiency and popularity have been debated, CRM training is now widely recommended by civil aviation authorities and adopted by other industries devoted to high reliability organizing (Flin et al., 2008; Weick et al., 2008). In the latest versions of CRM, human error is recognized as inevitable, and strategies aim at avoiding, trapping and mitigating consequences of error (Helmreich et al., 1999). Flin et al. (2008, p. 247) claim that this approach is a prerequisite for applying CRM as protection against human limitations.

Different categories of travellers in avalanche terrain will have different motives and imperatives for being there, of which recreationists have the highest degree of freedom in their choice of time and place for their activities. Most avalanche professionals, like guides and avalanche forecasters, may also freely choose terrain complexity, despite experiencing pressure and expectations from schedules, clients and employers (Johnson et al., 2016). Rescuers experience the least degree of freedom, as they cannot choose another place, another time. They are truly on the horns of a dilemma, having to balance their own safety against the survival of other human beings (Paper III).

Albert R. Jonsen (1986, p. 174), ethicist by profession, introduced "The Rule of Rescue" in his discussion on priorities in healthcare in the light of utilitarianism. He concluded that medical measures that may prevent death or prolong life constitute a formidable barrier to "felicific calculus", a scientific measure of what matters in decision-making.

> "I call this barrier the rule of rescue. Our moral response to the imminence of death demands that we rescue the doomed. We throw a rope to the drowning, rush into burning buildings to snatch the entrapped, dispatch teams to search for the snowbound...The imperative to rescue is, undoubtedly, of great moral significance; but the imperative seems to grow into a compulsion, more instinctive than rational".

This phenomenon affects most aspects of medical intervention (McKie & Richardson, 2003), also how we conduct mountain rescue operations. Somewhere along the axis from imperative to compulsion, we need to define and explain the concept of overcommitment.

John S. Ash and Clive Smallman (2008) studied the effect of overcommitment on decision makers` choice of rescue mode: defensive or offensive. They suggested that a statutory obligation to act, fear of scrutiny of rescuers, high expectations from the society and victim allegiance may force rescuers into overcommitment. In their study, overcommitment was defined as "rescue attempts in circumstances that were judged too risky to personnel by the expert cohort" (2008, p. 43).

2.5 Monitoring of accident risk in the avalanche rescue service

In risk management, Safety Information Systems (SIS) are established to enable comparison of the current safety level with safety goals (Aven et al., 2004). SIS data normally shows the "HSE cost" in the production, in the form of historical data on undesirable incidents, injuries and accidents. These are commonly called “lagging” risk indicators. By analysing SIS data, organizations may (Aven et al., 2004):

- Monitor the current safety level
- Identify risk factors
- Identify causes to adverse events
- Evaluate the effect of safety measures and activities
- Provide a basis for prioritizing between measures

In the Norwegian avalanche rescue service, there is no systematic documentation of HSE-related parameters. Since historical data may be scarce and because conditions may change over time, there is a need to identify predictive indicators of risk: “Given such a perspective, finding indicators that allow an organization to act before something happens, i.e. to be leading, rather than reactive and lagging, is a main challenge” (Herrera, 2012, p. 1).

In a proactive approach, it is necessary to describe and understand how the avalanche rescue system performs during normal operations, to identify factors of success, as well as the true origins of undesirable incidents (Hollnagel, 2013; Hollnagel et al., 2015). The challenge is to adopt reliable and valid indicators that allow us to anticipate how future accidents may occur. The term "anticipate" also includes the uncertainty associated with the selection and assessment of relevant variables. Andrew Hale (2009, p. 479) points out that “It is also necessary that the leading indicators can be shown to correlate with the lagging ones”, as a proof of validity. This “necessity” could pose a practical-epistemological problem, as correlation does not imply causation (Skog, 2004, p. 37). The effect of risk influencing factors on rescuer safety is seldom direct, close in time or always observable (Hume, 2003). Thus, the causal relationship is explained by logical induction. In this respect, to explain why an accident happened will always be easier than to predict that an accident will happen. Hale recommends adopting a standard scientific approach in the selection and evaluation of risk indicators (2009, p. 480).

Thorsen and Njå (2014) studied how major accident risk in offshore oil and gas activities was monitored, and they developed a set of leading technical, operational and organizational risk indicators. They linked their 16 leading risk indicators to six risk influencing factors (RIF), of which “Monitoring technical barriers”, “Planning of activities”, “Competence and training” and “Information about risk” could be relevant in this project. In their conclusion, they found it important to build understanding and ownership of a limited set of indicators, and to communicate the proactive and predictive value of leading indicators to key personnel.

In a major accident risk perspective, lagging risk indicators may not detect important systems-based causal factors (Leveson, 2011, 2015; Thorsen & Njå, 2014). Nancy Leveson introduced system-specific assumption-based leading risk indicators (2011, 2015), stating that major accidents result not from single component failure but from loss of control in the socio-technical system. The approach is based on the accident model, “System-Theoretic Accident Model and Processes” (STAMP) and rooted in Assumption Based Planning (APB) (Dewar, 2002; Dewar et al., 1993). Dewar et al. (1993, p. 5) define an assumption as: “…an assertion about some characteristic of the future that underlies the current operations or plans of an organization”. In Leveson`s perspective, then (2015, p. 8), “A leading indicator is a warning signal that the validity or vulnerability of an assumption is changing”. STAMP's starting point is that accidents happen when safety constraints are violated, and the associated “Systems Theoretic Processes and

Analysis” (STPA) technique is designed to aid the identification of scenarios that may lead to violation of constraints. The leading indicators derive from the assumptions on which system design and operation is based and assumptions about the system`s vulnerability to changes. In a bow-tie-like approach, “shaping” and “hedging” actions are applied to maintain the integrity of the assumptions. The approach requires comprehensive documentation of assumptions and indicators, and Leveson brings up the question of the feasibility (2015, p. 32) “of documenting and checking all the vulnerable assumptions in complex systems”. She states that documentation of the assumptions included in engineering is anyway recommendable, and that “The process of documenting assumptions (design rationale) can be justified for more than a leading indicators program”.

3 Methodology

3.1 Scientific approach

The research presented in this thesis was conducted within a complex socio-technical system. Recollecting that the main aim of the project was *to contribute to new knowledge,* the intermediate objectives were to describe, explore, interpret and explain various phenomena pertaining to both natural and social science. Theories existed before the commencement of the various studies, as a basis for study design. Theories also developed from the studies, on which conclusions and recommendations were based. In this context, theories are defined as specified relations between various phenomena, factors and variables (Skog, 2004, p. 18).

The scientific process of induction, in which detailed data about isolated events is accumulated and used to formulate general hypotheses, was incrementally established as the backbone of science. Results from experiments and observations were considered factual evidence, as opposed to speculation and clerical authority based on meta-physical interpretations.

Inductive methodology, considered by many to represent the line between science and non-science, was first questioned by David Hume (1711-1776), a Scottish philosopher, as he claimed that conclusions based on observations of certain phenomena in the past will not necessarily show regularity and hold good in the future. This is, also today, the classical objection against using statistical frequencies to predict future events. Hume presented three distinct constraints for a causal relation to be fulfilled: the cause must appear prior to the effect, close in time and always produce the same effect. Hume, the sceptic, eventually compromised and concluded that inductive reasoning is a human trait, determining the way we think (Magee, 1973). Bertrand Russell (1872-1970), a supporter of Hume on the problem of induction, concluded that, without the independent logical principle of induction, "Science is impossible" (Magee, 1973, p. 21).

To approach the problem of induction, Karl Popper introduced the concept of falsification; the true scientific task is to seek observations that would contradict the theory. A theory, then, is only valid to the extent that observations do not falsify it (Popper, 1976). Popper denied the existence of ultimate sources of knowledge, leaving all sources and suggestions open to criticism. His main point, rooted in critical rationalism, was that a search for ultimate sources of knowledge should be substituted by criticizing the theories presented by others and, above all, those presented by ourselves.

The work presented in this thesis required a holistic approach and methodological pluralism (Skog, 2004). Mixed methods research (MMR) is positioned between quantitative and qualitative research, with a primary philosophy of pragmatism (Johnson & Onwuegbuzie, 2004). It is an approach to knowledge "that attempts to consider multiple viewpoints, perspectives, positions and standpoints" (Johnson et al., 2007, p. 113). Johnson and Ogwuebuzie argued that MMR is "the third research paradigm", while recognizing that "Both quantitative and qualitative research are important and useful" (2004, p. 14). By this term, they referred to "research culture" as comprising "beliefs, values, and assumptions that a community of researchers has in common regarding the nature and conduct of research" (2007, pp. 129-130). Guba and Lincoln describe research paradigms as "the most informed and sophisticated views that its proponents have been able to devise" (1994, p. 108). As these research paradigms are human constructions, they can only be defended by persuasiveness rather that proof.

One important aim of MMR is to strengthen content validity, and Newman et al. (2013, p. 244) argue that trustworthiness is increased by "triangulation of data sources, expert debriefing, and peer review". From the perspective of constructivism, trustworthiness encompasses "credibility (paralleling internal validity), transferability (paralleling external validity), dependability (paralleling reliability, and conformability (paralleling objectivity)" (Guba & Lincoln, 1994, p. 114).

Since qualitative and quantitative approaches add different data on the same phenomena, mixed methods will broaden the knowledge base and strengthen our belief that the applied methods measure what we believe that they measure. Triangulation can be applied to sources of data, data analysis, investigators, methods and theories (Thurmond, 2001), increasing the angle of view and the ways a phenomenon can be interpreted. Thurmond also points to some specific disadvantages of triangulation (2001), of which the time needed to complete the studies and an abundance of data seemed most relevant in this project.

This thesis is, thus, written from the perspectives of critical realism and post-positivism, to gain insight into and experience of the system under study (mainly Papers I, II and III), and social constructivism when trying to understand and predict future states (mainly Papers II, IV and V) (Clark, 1998; Cruickshank, 2012). Figure 2 illustrates how research perspectives may change as the angle of view is shifted from retrospective to prospective.

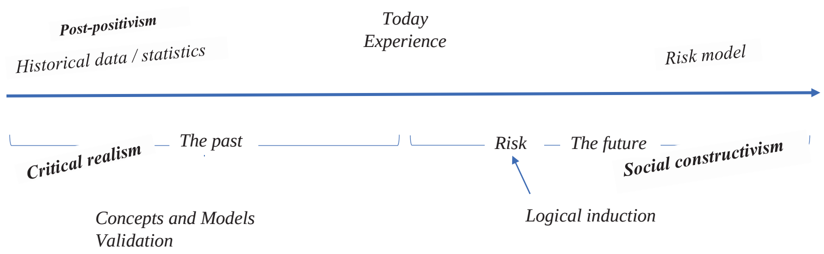

Figure 2. Research perspectives. The shifting perspectives of research as the angle of view turns from retrospective to prospective. Illustration developed in conversation with Professor Ove Njå, University of Stavanger.

An important reconciliation in post-positivism is that both numerical and non-numerical data are acceptable as blocks in building knowledge, thus including methodologies of interpretation. The stance taken in perspectives will, naturally, guide and limit the scope of research, the choice of methods, samples and analysis techniques (Ponterotto, 2005). Guba and Lincoln (1994, p. 116) conclude that "Paradigm issues are crucial: no inquirer, we maintain, ought to go about the business of inquiry without being clear about just what paradigm informs and guides his or her approach". A diversity in perspectives should counteract incompleteness and enhance the overall credibility of the results (Thurmond, 2001).

3.1.1 Study design

Four separate studies resulted in five papers. The studies presented in Papers I-IV informed the safety analysis reported in Paper V. All papers informed the analyses and conclusions of the thesis (Figure 3). The thesis, thus, results from a multi-study, mixed methods triangulation approach. Ideally, results from the various studies should be kept separated until the final synthesis, but this is not achievable in practice.

There may also be good reasons for informing subsequent studies with the factual results from former inquiries, e.g. statistics.

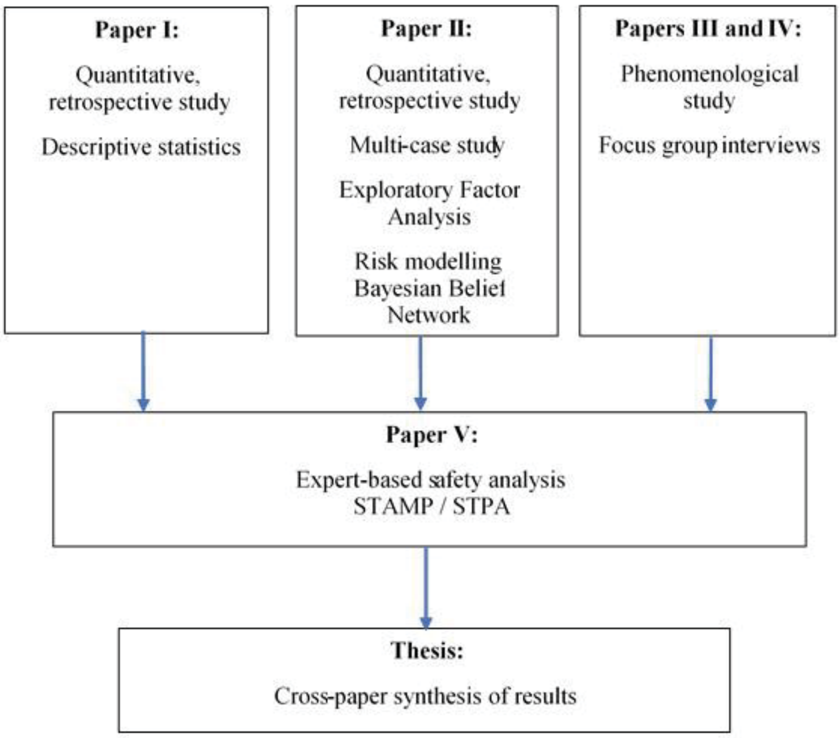

Figure 3. Study design. Papers I-IV informed the safety analysis reported in Paper V, and all papers informed the cross-paper findings, as well as the discussion and conclusion included in the thesis.

The following is a brief overview of the papers and the associated study designs. See also Table 1.

Paper I reports an empirically based retrospective quantitative study. Data from all 720 recorded Norwegian avalanche incidents in the period 1996-2017 was analysed and interpreted. The tendencies derived by analytical generalization (Polit & Beck, 2010) formed a basis for building knowledge and theories regarding patient and rescuer safety.

Paper II reports a comprehensive study originating from my Master thesis, “Norwegian rescue teams' avalanche risk assessment and management in road related avalanche rescue operations” (Lunde, 2015). A retrospective quantitative study of all Norwegian road related avalanche incidents in the period 1996-2014, combined with a case by case analysis of 45 road related avalanche rescue operations and an exploratory factor analysis (Comrey & Lee, 2013) of risk assessment and management activities, served as input to the modelling of performance in Norwegian road related avalanche rescue operations.

Papers III and IV report the findings of a phenomenological study comprising nine focus group interviews (P. Plummer-D'Amato, 2008a; Prudence Plummer-D'Amato, 2008b) of Helicopter Emergency Medical Service (HEMS) crew members in the Norwegian Air Ambulance Service. The aim was to explore the concept of overcommitment and to derive specific strategies to manage overcommitment in Norwegian medical evacuation and rescue operations.

Paper V reports an expert systemic safety analysis of the Norwegian avalanche rescue service. The analysis was based on the STAMP approach (Leveson, 2011) and conducted in accordance with the STPA method (Leveson, 2013). The seminars and subsequent analyses resembled focus group interviews. The aim was to derive a systems analysis of the Norwegian avalanche rescue service and to evaluate the applicability and feasibility of the STAMP/STPA approach in a multi-organizational context.

Table 1. Research papers with methods, populations and aims.

Article title	Research methods and activities	Population	Overall thesis aim	Study aims
Patient and rescuer safety: recommendations for dispatch and prioritization of rescue resources based on a retrospective study of Norwegian avalanche incidents 1996–2017	Analysis and descriptions of Norwegian avalanche incidents in the period 1996-2017, focussing on dispatch and prioritization of rescue resources	All JRCC-recorded Norwegian avalanche incidents 1996-2017 (Total N) Specific focus on incidents 2010-2017	To contribute to new knowledge about factors that are important for risk management and performance in the Norwegian avalanche rescue service	To present a basis for evaluation and necessary adjustments in dispatch, prioritization, and management of Norwegian avalanche rescue operations
Rescue performance in Norwegian road related avalanche incidents	Analysis and characterization of Norwegian road related avalanche incidents in the period 1996-2014 Case by case analysis of rescuers' degree of exposure to avalanche risk and their assessment and management of avalanche risk Exploratory factor analysis Qualitative and quantitative modelling (Bayesian network)	All JRCC-recorded Norwegian road related avalanche incidents 1996-2014 (Total N) Specific focus on incidents 2010-2014	To contribute to new knowledge about factors that are important for risk management and performance in the Norwegian avalanche rescue service	To present a model of Norwegian avalanche rescue performance, based on the characteristics of Norwegian road related avalanche incidents, the rescuers' degree of exposure to avalanche risk and their assessment and management of avalanche risk in these operations
The concept of overcommitment in rescue operations. Some theoretical aspects based on empirical data	Focus group interviews	30 Helicopter Emergency Medical Service crew members from five bases in four regional health authorities	To contribute to new knowledge about the concept of overcommitment in rescue operations	To describe and define overcommitment as a uniform concept in rescue operations
Overcommitment: Management in Helicopter Emergency Medical Services in Norway	Focus group interviews	30 Helicopter Emergency Medical Service crew members from five bases in four regional health authorities	To contribute to new knowledge about the management of overcommitment in rescue operations	To identify individual approaches and organizational strategies that counteract overcommitment
A systems thinking approach to safety in Norwegian avalanche rescue operations	System-theoretic process analysis	A group of 6 experts from representative managerial levels and organizations in avalanche rescue	To contribute to new knowledge about factors that are important for risk management and performance in the Norwegian avalanche rescue service	To investigate the ability of The System-Theoretic Accident Model and Processes (STAMP) approach to reveal weaknesses in and between services involved in Norwegian avalanche rescue missions

4 Results

This chapter offers a summary of results from the various studies. In the final section, isolated statistics, observations and statements are used to synthesize findings across papers.

4.1 Paper I

Patient and rescuer safety: recommendations for dispatch and prioritization of rescue resources based on a retrospective study of Norwegian avalanche incidents 1996–2017.

Aims: To present a basis for evaluation and necessary adjustments in the dispatch, prioritization, and management of Norwegian avalanche rescue operations.

Results: The Norwegian JRCCs have registered 720 snow avalanche events, with a total of 568 avalanche victims, of which 120 (21%) died. Including those fatally injured, a total of 313 avalanche victims in 209 accidents were treated as patients (55%), and we saw > 1 patient in 24% of these operations. Norwegian avalanche victims were partially or completely recovered prior to the arrival of rescuers in 75% (n = 117) of all rescue operations. In the remaining 25% of cases, the rescue service located 62% (n = 55) of the avalanche victims visually or electronically. In 50% of the 720 incidents, rescuers spent time searching in avalanches with no victims.

Conclusions: This survey indicates that we have experienced a shift in Norwegian avalanche rescue: from a search for missing persons in the avalanche debris to immediate medical care of already-located patients. The findings suggest that a stronger focus on both patient and rescuer safety is necessary. The patients must be ensured the right treatment at the right place at the right time, and the allocation of rescue resources must reflect a need to reduce exposure in avalanche terrain, especially in cases with no affirmed victims. The conclusions point to a stronger focus on performance measures rather than habitual, structural thinking.

4.2 Paper II

Rescue performance in Norwegian road related avalanche incidents.

Aims: To present a model of Norwegian avalanche rescue performance, based on the characteristics of Norwegian road related avalanche incidents, the rescuers` degree of exposure to avalanche risk and their assessment and management of avalanche risk in these operations.

Results: The annual average of road related avalanche incidents doubled to 11.6 in the five-year period from 2010-2014, compared with the preceding period, 1996-2009. Of the 135 recorded 1996-2014 avalanche incidents, 110 had no victim involvement (81.5%). In the remaining 25 recorded accidents, 11 out of 34 avalanche victims died (32.4%). In the period 1996-2014, no vehicles or victims were completely covered by avalanche debris, and, subsequently, none of the avalanche victims required location by traditional means.

Two-thirds of the 2010-2014 incidents happened during considerable avalanche danger (EAWS, 2016) and, in 12 out of 45 operations (26.7%), rescuers stayed and worked in avalanche runout zones when danger of naturally released avalanches was imminent. Rescuers were not exposed in 10 of the 45 rescue operations (22.2%). Members of the rescue service, measured through five chronologic phases of rescue operations, deviated regularly from the prescription for avalanche risk assessment and risk management. The degree of rescuer exposure was highly correlated with deviations from the prescribed avalanche risk assessment and management activities (0.84).

A factor analysis (Comrey & Lee, 2013; Starkweather, 2014), based on the registration of deviations, supported the isolation of three latent factors, denoted: I: Degree of avalanche risk awareness; II: Degree of commitment, and III: Degree of application of risk-reduction measures and mitigation.

Based on the overall results and obtaining expert judgement (Aven, 2014; Vick, 2002), we constructed a Bayesian network consisting of 34 variables. The qualitative and quantitative modelling showed that the Norwegian rescue service demonstrates acceptable performance in six out of ten road related avalanche rescue operations. Acceptable performance is achieved when due concern is paid to the safety of both rescuer and patient.

Conclusions: Reported road related avalanche incidents, with no observations of involved vehicles, no reports of missing people along the road section in question, no visible signs on the surface of the avalanche and no other circumstantial indications of an accident, commonly have no involved victims. Therefore, in such cases, high-risk search operations should be substituted with careful, planned and risk-minded investigations to clarify the situation. Excessive exposure of rescuers in avalanche runout zones can be linked to deficiencies in the acquisition and flow of information in the alert and dispatch phase, inadequate deployment of competent personnel and over-commitment. This could explain inadequacies in the avalanche risk assessment and management. The modelling of avalanche rescue performance with Bayesian Belief Networks proved its function as a useful and transparent diagnostic tool, aiding the identification and evaluation of risk influencing factors.

4.3 Paper III

The concept of overcommitment in rescue operations. Some theoretical aspects based upon empirical data.

Aims: To describe and define over-commitment as a uniform concept in rescue operations, based upon empirical data.

Results: Focus group interviews with crew members in the Norwegian HEMS revealed *"cost benefit"* as a term to summarize their considerations about degree of commitment during rescue missions. In this context, cost is an undefined measure of life-threatening "risk", whereas benefit reflects the patient`s prognosis, given the assistance from air ambulance personnel. *"Cost benefit"* considerations rest on four main pillars: patient situation, rescuer situation, triage and rescuer robustness. Their comments also aided the identification of eleven causal factors which may affect degree of commitment: personal affection and risk willingness; tunnel vision and target fixation; mission creeping; lack of knowledge; demanding, low frequency events; low-risk high-frequency events; equipment availability; expectations and external pressure; post-quiescence syndrome; unforeseen events; organizational overcommitment.

Conclusions: The reflections of air ambulance personnel broaden the concept of overcommitment to also include regular, everyday actions as hazardous rescue attempts in extraordinary incidents. Their examples draw a fine, blurry line between a necessary change of pace, to reach the patient in time, and impetuous actions, putting their lives in danger.

The study yielded this definition of over-commitment in medical evacuation and rescue operations: "Situations where rescuers make themselves or others vulnerable by committing more than is feasible, desirable, expected, recommended or compellingly necessary in the given scenario, and thereby run the risk of personal injury or death".

4.4 Paper IV

Overcommitment: Management in Helicopter Emergency Medical Services in Norway

Aims: To identify individual approaches and organizational strategies that counteract instances in which rescuers commit more than is feasible, desirable, expected, recommended, or compellingly necessary.

Results: Air ambulance personnel pointed to sociological, cognitive, and organizational elements that may influence their degree of commitment in challenging and hazardous rescue situations. Twelve commitment-moderating factors were identified: anticipation; contingency planning; communication; cue recognition; equipment and sensors; experience; risk and vulnerability awareness; quality and flow of information; training and preparedness; standard procedures; teamwork behaviour. The nontechnical, commitment-moderating activities used by HEMS personnel to stay safe in a complex rescue environment, named *"Operational Uncertainty Management"* by the authors, could be linked to tactics of coping with uncertainty based on the RAWFS heuristic (Lipshitz & Strauss, 1997) and elements of mindfulness (Weick et al., 2008). RAWFS is an acronym labelling the five coping strategies: Reducing uncertainties, Assumption-based reasoning, Weighing pros and cons, Forestalling and Suppression of uncertainty.

Conclusions: HEMS personnel describe a team-based approach to adjust their level of commitment in medical evacuation and rescue missions. Their organizational structure, on-base duty time, CRM training, and frequent debriefing of missions enhance trustful and direct online team talk. They rely on a combination of nontechnical skills, standard operational procedures, and organizational measures to identify and avoid harm's way.

4.5 Paper V

A systems thinking approach to safety in Norwegian avalanche rescue operations.

Aims: To investigate the ability of the STAMP (Leveson, 2011) approach to reveal weaknesses in and between services involved in Norwegian avalanche rescue missions. By conducting a STPA (Leveson & Thomas, 2018), we wanted to:

1: Identify goals, hazards, requirements and constraints.

2: Derive a safety control structure for the Norwegian avalanche rescue service.

3: Identify recurrent unsafe control actions in the Norwegian avalanche rescue system.

4: Evaluate STAMP and STPA as methods for analysing risk and safety in the Norwegian avalanche rescue service.

Results: Experts derived goals, hazards, requirements, constraints, a safety-control structure and unsafe control actions from a STAMP-based analysis of three avalanche rescue operations. The gap analysis revealed that both dispatchers and emergency personnel lack recommended training. First responders from the ordinary emergency services also lack basic avalanche safety equipment. This points to failing assumptions as regards compliance with safety requirements, the operationalization of the safety control structure and what is common avalanche rescue practice in Norway.

Conclusions: Goals, hazards, requirements, constraints, a safety control structure and common explanations for recurrent unsafe control actions were identified. Contrary to critics, systemic accident analysis proved manageable and productive, as it unceasingly directed the analyst's attention towards organizational challenges at the blunt end.

4.6 Main findings across studies

In this section, common findings across the studies are presented. The selection is not complementary, and the findings are supported by a varying number of the completed studies. The selection is based on related statistical results, observations and statements. By a process of *"analytic generalization"* (Polit & Beck, 2010, p. 1453), the expressed findings are, thus, identified by converging evidence derived from the various papers.

- *Call-out and dispatch of rescue resources to avalanches with no victims involved is common.*
    - In 50% of all avalanche incidents and 81% of road related avalanche incidents, no victims were involved (Papers I and II).
    - Qualitatively supported in Papers III and V, as the interviewees and experts talked about tendencies to deploy an excess of rescuers to avalanche incidents with uncertainty as to whether anyone was caught. In Paper III, this was named "Organizational overcommitment".

- *Overcommitment is common in avalanche rescue operations.*
    - The ratio of non-involvement operations to the total number of avalanche rescue missions is high (Papers I and II).
    - The frequency of undesirable incidents in avalanche rescue operations, as reported in Paper II and in Lunde & Kristensen (2013) has been consistently high, around 25%.
    - Observations of overcommitment are reported by important actors in this line of rescue work (Papers III, IV and V).
    - Around 40% of road related operations took place during the dark hours of the day (Paper II) and frequently in poor visibility.
    - Most of the rescue operations took place during considerable avalanche danger (Paper II).
    - A high frequency of deviations related to risk assessment and management activities (Paper II).

- *Variability in rescue response is common.*
  - Police incident commanders are not always present. As reported in Paper II, incident commanders from the police were present at the accident site in 61-72% of cases.
  - Air rescue resources are not always available or able to respond. Air rescue helicopters were activated / en route to road related avalanche incidents in 47-60% of cases (Paper II). HEMS helicopters and Air-Force-operated search-and-rescue helicopters responded to 325 and 184 of the 720 registered avalanche incidents, respectively, during the years from 1996 to 2017 (Paper I).
  - The frequency of deviations from a prescription for risk assessment and management varied between rescue operations (Paper II).
  - Observations reported by HEMS crew members (Papers III and IV) and experts (Paper V) indicated great variation in competency and preparedness amongst rescuers and rescue units.
  - Modelling of rescue performance showed a 63% probability of a safe and efficient avalanche rescue performance (Paper II).
  - Lack of compliance with regulations and recommendations (Paper V).

- *No avalanche accidents or incidents involving rescue personnel.*
  - None of the studies revealed that rescue personnel were directly involved in naturally released or self-triggered avalanches. Anecdotal evidence indicated that rescuers` vehicles were hit or blocked by avalanche debris, and that rescuers had to flee from flowing avalanche debris.

4.6.1. Risk indicators in the avalanche rescue service

Based on findings and recommendations in Papers II, III, IV and V, it appears important to operationalize indicators that allow the monitoring of:

- The degree of avalanche risk awareness
- The degree of commitment
- The degree of risk management and mitigation

The selection of risk indicators in this project was based on a definition derived from Thorsen and Njå (2014, p. 4): “A measurable quantity which may provide information about risk factors influencing rescuer and patient safety in avalanche rescue operations”.

According to Herrera (2012, pp. 20-21), risk indicators should be meaningful, sensitive, reliable, measurable, verifiable, inter-subjective, operational and affordable. The suggested leading risk indicators (Table 2) are formulated in accordance with these requirements and based on cross-paper findings and the system requirements presented in Paper V, Appendix A.

The indicators are also supportive of an assumption that:

- Avalanche rescue operations are to be handled by trained and experienced personnel at all levels, in planned and proficiently managed operations that consider both patient and rescuer safety, and in which all operative personnel carry the necessary safety equipment.

They are, thus, “developed to identify weakening effectiveness of the controls to enforce the safety constraints” (Leveson, 2015, p. 33).

In the subsequent interpretation of these indicators, small fractions are equivalent to the weak danger signs that sometimes precede major accidents (Weick et al., 2008) or signs of migration towards a higher risk level (Rasmussen, 1997). Recollecting Leveson's perspective, they may provide "a warning signal that the validity or vulnerability of an assumption is changing" (2015, p. 8).

Table 2. Suggested leading indicators of risk in avalanche rescue, based on cross-paper findings and the system requirements presented in Paper V, Appendix A.

Risk influencing factor	Leading indicators
Technical barriers	Fraction of operative personnel with avalanche safety equipment, personal GPS tracking device, and personal communication device/radio. Fraction of rescue operations with a complete set of safety equipment to all rescuers.
Planning / preparedness / management	Number of regional avalanche exercises per year. Number of interorganizational meetings per year. Fraction of formal debriefings following rescue operations. Fraction of operations where avalanche rescue specialists are called out. Fraction of rescue operations where the JRCC was notified immediately about avalanche incidents. Fraction of rescue operations where medical personnel were alerted immediately and deployed directly to the accident site. The ratio of completed search operations to the number of real rescues involving avalanche victims.
Competence and training	Fraction of personnel with basic avalanche training. Fraction of personnel with system-specific training. Fraction of rescuers whose training is overdue.

	Fraction of rescuers with interorganizational CRM training.
Information about risk	Fraction of personnel who have attended briefings on established safe meeting places along avalanche-prone road sections. Number of briefings on avalanche rescue response that personnel from the emergency services have attended during the winter season.

5 Discussion

The main aim of this project has been to contribute new knowledge on factors that are important for risk management and performance in Norwegian avalanche rescue operations. The initial two studies characterized avalanche rescue incidents, risk assessment and management activities, and avalanche rescue practice and performance. An exploratory study on overcommitment was conducted to increase the understanding of human factors in medical evacuation and rescue operations, and a safety analysis was conducted to evaluate the avalanche rescue system. The studies have offered information on structural, operational and individual aspects of avalanche rescue. In this section, the presented results are evaluated as to their ability to answer the research aims and questions.

5.1 Risk management – The balancing act

In this project, undesirable incidents and loss of barrier integrity have been considered weak signals of imminent danger. They also signal a disturbance of equilibrium, as weight is shifted towards either side: patient safety or rescuer safety. Is the avalanche rescue system correctly balanced to sustain the extra load of risk influencing factors, like uncertainty about the patient`s situation, variability in rescue resources and ever-changing environmental conditions?

The modelling of avalanche rescue performance presented in Paper II indicated that 6 out of 10 operations are conducted in a safe and efficient manner. Although the focus of this thesis has been to detect weaknesses in the overall avalanche rescue system, it is also important to dwell on the fact that many high-quality operations are carried out. Indirectly, the findings that point to flaws and weaknesses also point to factors of success. In the following, a balancing act is sought, illustrated by debating stabilizing and destabilizing factors in risk management in Norwegian avalanche rescue operations.

5.1.1 Stabilizing factors

Requisite variety

Previously, in Section 1.1.2, the Norwegian rescue service was referred to as an integrated project organization (Brandshaug, 2011). Although probably not the result of a specific design to achieve high reliability, the multi-organizational and multi-skill profile of the rescue service displays "a requisite variety" (Weick et al., 2008) that contributes to keeping operations reasonably safe. The rationale for this assertion was introduced by Schulman (1993, p. 358), as he pointed to "conceptual slack", i.e. "a divergence in analytical perspectives among members of an organization over theories, models, or causal assumptions pertaining to its technology or production processes", as a reliability-enhancing property. Conceptual slack encompasses both an excess of resources ("resource slack") and freedom in organizational activity ("control slack"), which relaxes the dependence on immaculate procedures and foresight.

Kruke and Olsen (2005) studied reliability-seeking networks and found that the collective ability to analyse problems from different perspectives contributes to enhanced anticipation, resilience and sound scepticism, thus also increasing the ability to cope with extraordinary situations (Masys, 2012).

The strategies recommended by HEMS crew members to recognize and manage overcommitment partly relied on requisite variety (Papers III and IV). The cross-trained, multi-professional three-man crews encourage each other to present different perspectives and opposing views, to avoid *"tunnel vision"* and other similar psychological phenomena which may affect their decision-making in challenging rescue missions.

Samvirke[1]

Schulman describes two types of conceptual slack: "resource slack" and "control slack" (1993, p. 353). It is tempting to see the volunteer rescue organizations, in particular, as representatives of "resource slack", and their decentralized structure of emergency preparedness as "control slack", both important assets of the Norwegian emergency preparedness principle, "Samvirke" (Regjeringen, 2015). Volunteer rescue organizations are not directly limited by economy in their activities; they organize their own activities and develop rescue methods and techniques.

The principle of "Samvirke" can be linked to "the rule of rescue" (Jonsen, 1986), in that it entails a voluntary and "deeply rooted willingness to help when accidents occur" (Aasland & Braut, 2018, p. 178). It utilizes, then, the enthusiasm that follows volunteerism (Bowen & Siehl, 1997; March & Simon, 1993) in two ways; one is the decision to participate and the other is an inherent wish to be utterly prepared for the job. In a variety of ways, local rescue resources are "communities of practice" (Wenger & Snyder, 2000) defined as "…groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (Wenger, 2011, p. 1). The result is locally developed knowledge and skills, which contribute to maintaining a certain level of expertise in avalanche emergency preparedness.

In this way, the benefits of requisite variety are institutionalized by the principle of "Samvirke". In a holistic perspective, transfer and overlap of

[1] *"Samvirke is a Norwegian word for a concept based upon a type of organisation with traditions going back hundreds of years, as well as a principle for cooperation and collaboration. Still it is something more than and different from collaboration. Samvirke carries values as confidence and common understanding. By tradition, samvirke is based upon voluntary and open membership and democratic governance"* (Aasland & Braut, 2018, p. 1).

tasks and responsibilities between multi-organizational rescue units may also compensate for variability in rescue unit presence, competency and degree of preparedness. Since "Samvirke", in effect, invites local rescuers from different professions, with firm knowledge of local conditions, to be prepared for a variety of rescue situations, it is here considered an important stabilizing factor in risk management.

Individual capacities

The framework constituted by local rescue organizations further stimulates a development of individuals` knowledge, skills and attitudes. Several authors (Leveson, 2011; Rasmussen, 1997; Reason, 1997) have pointed to the importance of individual assessment and action to maintain control in emergencies. The activities of individuals may even deviate from standard procedures, as a necessity to remain in control of a critical situation. “This operator variability reflects a capacity of human operators to respond creatively to shifting contexts” (Rasmussen & Suedung, 2000, p. 66).

Paper V’s findings point to a decentralized responsibility for assessing risk in avalanche rescue operations. One of the interviewees named this phenomenon: “Outsourcing of control actions to the next level…”. In this respect, competent decision-making by the individual front-end rescuers may compensate for inadequate control algorithms at a higher level (Reason et al., 1998; Weick et al., 2008). Leveson (2011) argues that front-end personnel are not always capable of making safe decisions, pointing to the importance of system-level information for sound decision-making. System-level information in avalanche rescue operations could be regional and local avalanche risk, knowledge of other rescue resources approaching from different directions, and information about the patient`s situation (cost-benefit; Paper III).

Individual capacities as safety barriers are not necessarily visible in plans and reports of organized rescue activity, which implies that the effect of individual skills on operative risk management is not easily measured, perhaps only noticed as low accident rates. In oversimplified hindsight analyses, sharp-end actors are more easily identified as “the culprits” in cases of accidents (Rasmussen, 1997; Reason, 1997).

Buffers

The findings reported in Papers III and IV, on overcommitment, seem to support the impression that the individuals` perception of risk and how they communicate this to their fellow rescuers is a major factor in managing operational risk. Crew members accentuated critical questions as an important approach to avoid common pitfalls of overcommitment. This is in accordance with the concept of *“Red teaming”* (Masys, 2012), i.e. to encourage different perspectives. The HEMS crew members maintained that this capacity is linked to knowledge, experience and teamwork behaviour. Due to the variability in the rescue service, an adequate level of training and experience cannot be expected in all rescue units participating in avalanche rescue. Specially trained rescue personnel, often air rescue crew members, therefore, constitute important *"buffers"* between less experienced personnel and demanding rescue situations.

This, of course, also points to a major vulnerability in the system: what happens when rescue operations, by coincidence, are handled by less experienced personnel through all managerial levels? This question is partly answered by Papers II and V, pointing also to weaknesses in control algorithms at dispatch centres as a lack of risk assessment activities in later rescue phases. “Most accidents in well-designed systems involve two or more low-probability events occurring in the worst possible combination” (Leveson, 2011, p. 34).

The National Guidelines for Avalanche Rescue

The establishment of national guidelines for avalanche rescue in 2007 (NRR, 2012) have played an important role in standardizing rescue procedures. The guidelines function as a "Book of Knowledge", "a database that…capture the relevant knowledge that (rescuers) need to do their job, including compliance standards, best practices and lessons learned…" (Wenger et al., 2002, p. 3). As a common platform for communication across organizational borders between professional and non-professional rescuers, the guidelines further stimulate knowledge building and risk awareness in the communities of rescue practice. A major challenge is that financial and time constraints may lead important actors in the rescue service to disregard recommendations presented in guidelines. Risk management in avalanche rescue operations could benefit from converting some parts of the guidelines for avalanche rescue into strict rules, also for the managerial levels in the rescue service (Hopkins, 2011). Challenges linked to "procedural overspecification" (Reason et al., 1998, p. 291) and non-compliance will be discussed in the next section.

5.1.2 Destabilizing factors

The systemic safety analysis presented in Paper V seemed to summarize the results presented in Papers I and II and supported the theory of overcommitment presented in Papers III and IV. The following over-arching topics stand out as possible explanations for heightened risk levels for patients and rescuers.

Inadequate control algorithms

Paper V reports that inadequate control algorithms were frequent common causes of unsafe control actions. The unsafe control actions defined by Leveson (2011) are:

1. An unsafe control action is provided that creates a hazard.

2. A required control action is not provided to avoid a hazard.

3. A potentially safe control action is provided too late, too early or in the wrong order.
4. A continuous safe control action is provided for too long or is stopped too soon.

Dispatch procedures are seemingly not facilitating risk assessment activities in the initial stages of rescue operations. Reflected in Leveson's accident causation model (2011, p. 217), all four types of unsafe control actions were identified. Please see Paper V, Table 1 for further details.

In the study on road related avalanche incidents (Paper II), frequent deviations from normative risk assessment activities were linked to the regular exposure of rescuers in avalanche runout zones. A Bayesian Belief Network modelling of rescue performance showed that rescue management and dispatch of rescue resources are major determinants in safe and efficient rescue operations.

Undesirable incidents indicate a control problem, and control algorithms are keys to enforcing safety constraints in a socio-technical system (Leveson, 2011). Deficient and differing control algorithms may contribute to coincidental variation in performance, both within and between the various dispatch centres. This may also cause coordination risks. Coherent dispatch procedures are vital parts of dispatch decision systems when handling interdependent conditions within or between dispatch centres and managerial levels (Johnson, 2016; Leveson, 2011) (Paper V). In practical terms, omitting in-depth questioning of witnesses and an initial assessment of mission risk (Bründl & Etter, 2012; Kristensen et al., 2007) (Paper II) could deprive rescuers of important "framing" information (Perrin et al., 2001; Sadler et al., 2007), which may positively affect their risk perception and risk awareness (Papers III and IV). Framing could also affect the mental models we use when selecting strategies for problem solving (Endsley, 1995).

The retrospective study of Norwegian avalanche incidents presented in Paper I pointed to outdated control algorithms that systematically sub-optimize the possibility to offer avalanche victims swift and proficient prehospital care. The study showed that 55% of avalanche victims were injured and that 75% of victims were recovered by the time organized rescuers arrived at the scene of the accident. Despite this, helicopters were routinely detoured or kept waiting for other resources specialized in searching for victims. To uphold this response pattern could be seen as a system failure and a breach of professional standards: "The standard of performance under given conditions which takes into account recent knowledge and evidence-based norms and a standard of practice expected of a qualified, well-considered practitioner with similar experience in similar circumstances" (Helse og Omsorgsdepartementet, 2005; Saunes et al., 2010, pp. 25 and 31).

The importance of control algorithms is linked to both quality assurance and learning. Although strict compliance with all detailed descriptions in written instructions at dispatch centres is not to be expected (Rasmussen, 1997), control algorithms should represent best practice, thus ensuring optimal handling of avalanche emergencies. The analysis of deviations from a prescription for avalanche risk assessment and management reported in Paper II is a sort of feedback to dispatch centres. It is "a comparison of output measures, including performance, with organizational objectives…", serving as a basis for evaluation and adjustment of dispatch centre control actions (Reason et al., 1998, p. 290). The system goal identified in the systemic safety analysis (Paper V) was: "To provide safe and efficient rescue efforts in all conditions". The control algorithms at dispatch centres need to be adjusted to support this organizational objective. Reason et al. (1998, p. 290) state: "This type of control (job appraisal) is often necessary when tasks are complex and unpredictable".

Siri Wiig (2007, p. 10) conducted a multi-level case study on learning from errors in healthcare, concluding that "Different system levels are dependent on each other in the process of error prevention". In evaluation of rescue operations, the written algorithms function as a basis for transfer of experience and input to necessary changes in rescue practice. The group of experts involved in the systemic safety analysis (Paper V) identified that links between the dispatch of rescuers and risk assessment activities were missing. These links can be provided by continuously improved control algorithms.

Another question, which is not discussed in any detail in this thesis, is whether dispatch centre algorithms are designed to accomplish the suggested normative risk assessment activities. This could relate to differences in mental models between blunt-end designers of systems and front-end rescue personnel. Figure 4 illustrates how differences between mental models may arise in the avalanche rescue system (Leveson, 2011, p. 42) and subsequently cause disharmony in perspectives on important issues in avalanche rescue performance.

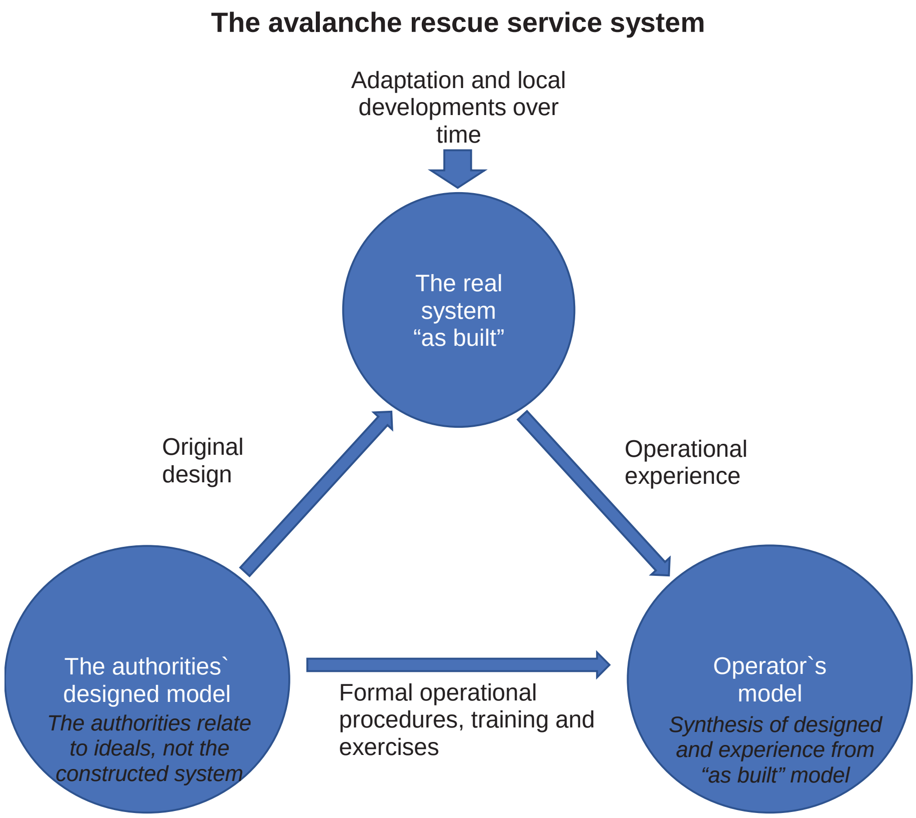

Figure 4. System design and mental models in the avalanche rescue service (Leveson, 2011, p. 42).

The analyses in this thesis are mainly conducted from the front-end perspective, since that is where rescuer and patient safety will be compromised. This means that dispatch centres may have been measured in tasks which they consider to be outside their responsibilities and design specifications (Paper II). Hence, dispatch centres are not staffed and trained to conduct and facilitate avalanche risk assessment and management.

The added strain of reforms in governmental agencies, causing "time pressure, stress, increased workload, and understaffing with a negative impact on the learning conditions within and across system levels" (Wiig, 2008, p. 46) could further compromise the capacity and competency of dispatch centres. This is also linked to the next topic: failing assumptions.

Failing assumptions

Given the assumption that the structure and hierarchy of the rescue service is designed for safe rescue practice, and that the operationalization of this design requires education, training, staffing and safety-minded control algorithms at all levels, the findings in this project point to serious gaps between theory and practice.

Paper V's findings indicate that the police, as a structurally visible and hierarchically important controller in the safety control structure of the rescue service, do not meet the expectations of instructions (Regjeringen, 1995, Nr. 16, 2005, 2015, 2018), guidelines (NRR, 2012) and recommendations (Bründl & Etter, 2012; Van Tilburg et al., 2017). This may contribute to a deficient control of rescue operations in the critical first hour. This is an example of an assumption that is failing (Leveson, 2011, 2015), and the assumption may be considered "load bearing" in Dewar`s terminology, thus requiring "significant changes in the organization`s plans" (2002, p. 66).

Practical changes are already clearly visible in that front-end management and coordination, to an increasing degree, is allocated to volunteer rescuers, the local fire brigade and the ambulance services. Descriptive statistics in Paper II showed that incidence commanders from the police were present at the accident site in less than 75% of cases. Despite lack of competence and avalanche safety equipment, police patrols were the most frequent first organized rescue responders in road related avalanche incidents. In backcountry accidents, a swift police response and presence is less common. Recent anecdotal evidence from newspapers also supports observations that incident commanders from the police arrive late, or not at all, in various types of emergencies.

Wiig (2008, p. 55) concluded that emergency management in the public sector is vulnerable to a "compound pressure between efficiency and safety" and therefore given less priority compared with other, mandatory tasks. Rescue management is only a minor part of the police portfolio, which may force leaders to downsize preparations for rather infrequent avalanche emergencies.

The assumption is also failing for other participants in avalanche rescue operations. The experts in the systemic safety analysis (Paper V) pointed towards similar deficiencies to those in the police in both the ambulance service and the fire and rescue departments. Avalanche rescue methodology or skills-based training is not a part of the standard education for first responders in these emergency services. This also implies that these units are generally not equipped with avalanche safety equipment.

Paper V discusses the implications of not complying with regulations and recommendations, with reference to Andrew Hopkins (2011), who recommended prescriptive rules to force "laggards" into line. This is, of course, a sensitive issue, if structurally important regulators (controllers) are themselves part of the problem. Sharp-end decision makers may choose not to comply with rescue procedures, as a necessary accommodation to dynamic situations (Rasmussen, 1997; Reason, 1997). Blunt-end non-compliance with training requirements, control algorithms and recommended risk assessment activities could affect the safety of sharp-end workers and patients, as indicated in Papers I, II and V. Ignorant rescue management could also force rescuers to overcommit, if rescue activities are wrongly initiated in hazardous conditions (Papers III and IV). An important aspect to consider in future discussions on this matter is that the safety control structure of the rescue service (Paper V) illustrates a top-down safety management, whereas the development of avalanche rescue procedures and recommendations, e.g. the guidelines for avalanche rescue (NRR, 2012), are exclusively a bottom-up activity. This also serves to illustrate that the police, although institutionally an operative partner in the rescue “samvirke”, are not an integral part of the “communities of avalanche rescue practice”.

Lastly, the variability in the rescue organizations is also indicative of vulnerable assumptions about proficiency in avalanche rescue management. The performance analysis presented in Paper II showed a 63% probability of efficient and safe rescue operations. The uncertainty about avalanche rescue performance could be linked to a mismatch between the assumptions on which the rescue service is designed and the practical feasibility of rescue plans and actions.

Inadequate avalanche risk assessments

Considering the required short response times in rescue operations (Brugger et al., 2001), a knowledge-based, high-quality avalanche risk assessment requires immediate and direct dispatch of acknowledged experts. The Norwegian National Guidelines for Avalanche Rescue (NRR, 2012) recommend that snow safety specialists are summoned to assist rescuers in complex operations. According to a government circular, experts from the Norwegian Geotechnical Institute can be called out to assist in rescue operations and situations requiring the evacuation of inhabited areas (Regjeringen, 1978).

The group of experts in the systemic safety analysis also identified the summoning of snow safety specialists as a safety requirement (Paper V, Appendix A). Avalanche rescue leaders are frequently called out to assist in avalanche rescue operations, but these are volunteers with variable training and experience in avalanche risk assessment. Paper II’s findings show that road related avalanche incidents often take place in periods with considerable-to-high avalanche risk, in darkness and limited visibility. Avalanche risk assessments in these conditions require specific and ample training, in addition to proficient use of specific map tools to assist the judgements (Caragounis et al., 2015). The later developments of the map tool "Regobs" by the Norwegian Water Resources and Energy Directorate (Engeset et al., 2018) demonstrates promising features, which offer valuable assistance in avalanche risk assessments, also for less skilled rescue personnel.

The Canadian BC Ministry of Transportation and Infrastructure (2017) demonstrates split roles in avalanche emergencies, where Avalanche Safety Officers focus on snow safety issues, whereas Task Force Leaders concentrate on the implementation of search and rescue techniques. A division of responsibility between safety assessments and rescue activities could ensure high-quality rescue performance and help prevent overcommitment in rescue efforts (Papers III and IV).

To remain in control of safety when responding to road related avalanche incidents, the rescue service could introduce level-based decision making as a safety constraint. Leveson discusses limitations to decentralized decision-making, stating that "Low level personnel can only make decisions in one direction, that is, they may only abort landings" (2011, p. 44). "Low level" in this context needs to be interpreted as low competence level. A similar approach was suggested by one of the experts in the systemic safety analysis (Paper V), in which a "NO" would be OK, whereas a "GO" would require a separate assessment from qualified personnel. This could prevent untrained and unequipped personnel from entering danger zones; however, it would increase the time needed for rescuers to arrive at the scene of accidents.

5.1.3 Overcommitment

The conflicting imperatives of rescue pose a serious challenge to the rescue system goals: safe and efficient rescue efforts in all conditions (Paper V). The exploratory study of overcommitment in medical evacuation and rescue operations yielded a surprisingly multifaceted picture of a phenomenon which seemed recognizable to the interviewees. Overcommitment was appreciated as an important topic, both in their demanding medical evacuation missions and in rescue operations requiring interorganizational efforts. They explained the anatomy of situations where rescuers could make themselves vulnerable by committing more than was feasible, desirable, expected, recommended or compellingly necessary. The crews also reflected on their own strategies to resist overcommitment, summarized in Paper IV as “operational uncertainty management”.

The autonomous response of geographically widespread rescue units poses a serious challenge to controlling overcommitment in the critical first hour of rescue operations. Risk perception and situation awareness are bound to differ due to inter-rescuer variations in background, training, experience and available “subsets of information” (Endsley, 1995, p. 39). Siri Wiig (2008, p. 57), who studied risk management in a parallel arena, found that “Risk perception within the specialized healthcare regime was heterogeneous and varied across regime levels”. The resulting differences in risk images across organizational borders affected the sharing of information and subsequently also how risk was managed.

The spatio-temporal differences in avalanche risk are reflected in the individual perspectives of rescuers approaching from totally different directions. Optimally, to achieve a high level of shared situation awareness across rescue units travelling in a complex environment requires a continuous exchange of safety-related information. Team situation awareness in these situations would be “the sum of operator perception and comprehension of information and the ability to make projections of system states on this basis” (Kaber & Endsley, 1998, p. 43). In short, a state where decision makers can sense, grasp and predict future developments.

Added to the challenges linked to flow of information and individual and team differences in risk perception, the geophysical uncertainty of snow avalanches leaves rescuers with an undefinable residual uncertainty. Even if all available information about local weather, snowpack and terrain was distributed, uncertainty would still exist about the probability of avalanche release and runout lengths (McClung & Schaerer, 2006; Schweizer, 2008). The study of rescue performance in road related avalanche incidents (Paper II) indicated frequent exposure of rescuers in avalanche runout zones during avalanche cycles (undesirable incidents). Questions arise, then, about the rescuers` conceptualization of uncertainty and the related coping strategies (Lipshitz & Strauss, 1997). Clearly, forestalling was a visible strategy when rescuers reportedly retreated from rescue activities to avoid avalanche hazard. Knowing the residual uncertainty of avalanche prediction, and that further avalanche risk assessment was hampered by darkness and reduced visibility, suppression of uncertainty seems the most likely strategy in at least some of the undesirable incidents identified in this study. This conclusion is somewhat contradictory to the findings of Lipshitz and Strauss (1997), which showed that suppression was the least likely used coping strategy when facing all types of uncertainty. Mikkel Bøhm (2017, p. 106), however, suggests that suppression is probably more common than previously anticipated.

The incidence of suppression of uncertainty is relevant, since the transition from other coping strategies to suppression seems to coincide with the transition of rescue efforts where “imperative seems to grow into a compulsion, more instinctive than rational” (Jonsen, 1986, p. 174). Overcommitment is, thus, linked to suppression of uncertainty.

The listed difficulties related to performance and safety in the process industry also seem relevant for the avalanche rescue service (Kaber & Endsley, 1998, p. 43):

- A failure to detect critical cues

- A failure to properly interpret the meaning of information
- A lack of understanding of individual task responsibilities and the responsibilities of other control operators
- A lack of communication between operators functioning in teams

The possible causes of overcommitment identified by HEMS crew members both initiate and exaggerate these difficulties, whereas the measures included in “operational uncertainty management” are intended to resist an unfortunate development towards overcommitment.

The concept of overcommitment was elucidated within the framework of three-man crews in the National Air Ambulance Service. The question is now whether it is possible to influence overcommitment across organizational levels in the rescue service.

The organizational overcommitment resulting in many and unnecessary high-risk – low-gain situations (searching in avalanches with no victims involved) (Papers I and II) could be reduced by evaluating and adjusting dispatch routines. A low threshold for activating an excess of rescue resources increases the complexity of coordination and communication, thus negatively affecting the conditions for collective risk awareness. It is also an example of “outsourcing of risk assessment” to front-end rescuers, which could increase the possibility that incompetent personnel are forced into typical overcommitment situations.

To counteract the pressure created by conflicting goals in socio-technical systems, Wiig (2008) recommended developing aims and measures which are recognizable and feasible at lower organizational levels. The HEMS crew members praised their repeated CRM training, which encouraged “team talk” (Gundrosen et al., 2016) to equalize situation awareness and to prevent errors.

Interorganizational training with an increased focus on CRM-like training and “red teaming” (Masys, 2012) could inspire the complex and multifaceted rescue organization to act like a team and thereby benefit from the added protection offered by team behaviour (Flin et al., 2008; Salas et al., 2005).

5.1.4 Monitoring of risk indicators

James Reason (1997) points to the importance of proactive measures that will cause a gain in organizational fitness. The activities to be monitored in the suggested set of leading risk indicators could offer a combined function as elements in a "fitness program" and as manageable organizational safety barriers, "determining a system`s safety health" (Reason, 1997, p. 114).

Jan Hayes (2012) advocated a focus on barrier performance rather than results from separate and uncertain risk analyses. Failing congruence between the intentions expressed by the safety control structure and the abilities of important actors in the rescue service is indicative of weakened barrier integrity. The findings of this thesis point to a nonchalant attitude to the integrity of the barriers which have been defined for avalanche rescue operations (NRR, 2012; Regjeringen, 2005, 2018). The reaction by operational personnel in Haynes` study was to stop production if barriers were lost, in danger of being breached, or even if the integrity of the barrier was questionable. A recommended action for managers in the rescue service could be to reiterate the intention of barriers and inspire the individual rescue organizations, including the public emergency services, to act promptly if the barriers are not working as intended. In future activities to mend and strengthen barriers, it will be important to operationalize and visualize the assigned responsibilities at all levels in the safety control structure. Only then will operative personnel be able to observe and evaluate organizational barrier integrity.

This thesis is currently a solitary voice in warning about potential weaknesses in the avalanche rescue safety systems. The establishment of the recommended set of leading risk indicators could both improve the organizational fitness of the avalanche rescue service and further contribute to validating the findings in this study.

The monitoring of risk indicators could be included in the regular auditing of the LRCCs conducted by the JRCCs. This finds support in already existing regulations: “The Joint Rescue Coordination Centre shall regularly monitor the Local Rescue Coordination Centres and ensure that these work in accordance with the instructions and recommendations given for the rescue service” (Regjeringen, 2015, 2018). At all levels, the set of indicators should be considered natural elements of both basic and advanced avalanche safety training programmes (NRR, 2012; Van Tilburg et al., 2017). After all, “It is as much about what people do with what they notice as it is about the activity of noticing itself” (Weick et al., 2008, p. 37).

5.2 Study strengths and limitations

Retrospective studies on historical data from Norwegian avalanche incidents formed the basis for statistical generalizations about avalanche victims and rescue operations (Papers I and II). The interpretation of this data material, along with qualitative data from focus group interviews (Papers III and IV) and the systemic safety analysis (Paper V), served as input to the subsequent analytical generalization (Polit & Beck, 2010), going from specific observations to general concepts. The generalizations represent our assumptions on how various mechanisms interact to produce the given result, “a working hypothesis”, which is highly contextual (Cronbach, 1975).

The systemic safety analysis further invited the views of expert “brothers in arms”, thus broadening the analytical perspective of the thesis. It could also counteract researcher bias, but Thurmond warns that like-minded analysts could also amplify already existing biases (2001). In our case, several of the participants shared similar backgrounds from volunteer mountain rescue organizations, but this also added to the in-depth understanding of avalanche risk assessment and management in the rescue service.

Co-authors of the various papers have also made significant contributions to the interpretation of the data material and the results. Likewise, many conscientious reviewers offered important input about data, analyses and results, which greatly improved our presentation of methods and results.

Over time, study results have been presented in several academic and rescue communities. These activities have thoroughly tested descriptions and analyses and contributed to the increased validity, credibility and transferability of results.

All in all, the triangulation of studies, methods and analysts strengthened our ability to understand the results (Thurmond, 2001) and constituted the holistic scope which is required in studies of risk management in a socio-technical system (Wiig, 2008).

Specific strengths and limitations of the various studies are presented in the respective papers. None of the studies in this thesis was a randomized experiment. No direct interventions were made in populations, but investigators may have influenced interview situations. The introduction of a topic alone may influence people's way of thinking about a specific phenomenon. This was a concern in the study of overcommitment, since we could not know beforehand whether interviewees were familiar with the expression. Therefore, the interviews followed a common structure, which included a short introduction on the topic, followed by open questions (Litosseliti, 2003). This procedure returned detailed stories from the operational world of HEMS crew members, as such both exploratory and descriptive in character. The use of a questioning guide, with necessary adaptations, was therefore considered adequate to support the exploratory nature of the study.

Likewise, in the systemic safety analysis reported in Paper V, the introduction of the STAMP/STPA methodology surely influenced the experts` way of thinking about safety in the Norwegian avalanche rescue service. This could also influence the discussions and the subsequent analysis of weaknesses and strengths in the avalanche rescue system. This created a need to balance necessary information about the methods and the aim of utilizing the individual experience of the participating experts.

The presented results, conclusions and theories presuppose causality. Causal knowledge is the cornerstone of predictions and planning. A cause is seen as a mechanism or phenomenon which has the capacity to produce certain effects. It is tempting to believe that an ability to explain a phenomenon also allows accurate predictions about the same phenomenon. The challenge is to go from descriptions to an in-depth understanding, since to understand implies trying to answer how and why certain mechanisms cause an effect (Skog, 2004).

It is pertinent to question our assumption of causality between registered deviations from a prescriptive tool for avalanche risk assessment and management, and rescuer exposure in avalanche-prone terrain (Paper II). The assumption rests on two main pillars: 1: Compliance with recommendations presented in avalanche bulletins, snow safety literature and training are expected to reduce avalanche accidents (Van Tilburg et al., 2017). 2: Organizational factors are important as direct or indirect causes of unwanted incidents and accidents (Reason, 1997). Attempting a further evaluation on the basis of the Bradford Hill criteria (Hill, 1965), we have shown a rather strong association between the perceived events, deviations and exposure (although seldom direct, close in time or always observable) (Hume, 2003). The association is coherent with (snow) safety, mountaineering and avalanche rescue literature. It is fair to expect a certain preventive effect of applying the prescribed activities, although one cannot expect a specific effect linked to all the individual activities. On lack of specificity, Hill (1965, p. 297) comments that "One-to-one relationships are not frequent". Since the analyses were performed by only one investigator, repeated studies are needed to conclude on the consistency of the registered deviations. An attempt to reduce the single-investigator challenge was made by using detailed data dossiers to document the evaluation of cases.

The effect of non-compliance with normative risk assessment and management activities, lack of information, lack of training, etc. are seen as possibly uncorrelated causes, yielding common effects (Waldmann, 1996): undesirable incidents where rescuers are overly exposed in high avalanche risk situations and patients who are not granted an optimal rescue response. The scientific process in this thesis thus follows the logical principles of induction, by accumulating isolated events to formulate general hypotheses about patient and rescuer safety.

6 Conclusion

The following is a short summary of important results and suggestions for follow-up studies on avalanche rescue practice.

The Norwegian avalanche rescue service seems to be caught off balance when facing the extra load of common risk influencing factors in rescue operations. The overall impression is that many rescue operations are carried out with high risk to rescuers, defined by the level of exposure sustained during missions (Paper II). Dispatch routines may have compromised the possibility of offering injured avalanche victims the right treatment at the right time in the right place (Paper I). Consequently, the standard rescue response in avalanche rescue operations needs to be adjusted to enhance both patient and rescuer safety. One typical example would be establishing a standardized use of safe meeting places in infrastructure-related avalanche incidents. Another would be to ensure immediate and direct dispatch of medical personnel to avalanche victims.

Safety in avalanche rescue operations is a system problem (Leveson, 2011; Rasmussen, 1997), and accidents occur when safety constraints are breached. Safe rescue practice constrains the activities of the participating organizations within a reasonable degree of freedom, to allow necessary front-end decisions to be made. The safety constraints acting on the avalanche rescue service are already laid down in instructions, regulations, handbooks, guidelines and recommendations (Helse og Omsorgsdepartementet, 2005; NRR, 2012; Regjeringen, 2005, 2015, 2018). Further work on safety in the rescue service could benefit from a focus on compliance with the established safety constraints, especially at the blunt end. This could also ensure that avalanche rescue practice corresponds to the assumptions underlying the existing safety control structure (Paper V).

The concept of overcommitment could provide a basis for both real-time adjustment and retrospective evaluation of commitment in rescue operations. Pertinent questions, as to whether rescuers make themselves or others vulnerable by committing more than is feasible, desirable, expected, recommended or compellingly necessary in a given scenario, could induce learning and reduce the risk of personal injury or death.

Avalanche rescue performance could benefit from a change of focus from a predominantly skills-based training to operational uncertainty management (Paper IV), in line with the appraised CRM training of HEMS personnel. This should include measures to enhance avalanche risk awareness, commitment moderation and avalanche risk mitigation (Paper II).

The value of the various analyses and results included in this thesis may serve as input to discussions on risk acceptance levels in the rescue service, the applicability and validity of control algorithms in rescue management and how to adjust the degree of commitment in various rescue missions.

6.1 Follow-up studies and activities

- The incidence of rescuers exposed in runout zones (Paper II) and direct travel to accident sites (Lunde & Kristensen, 2013) in high avalanche risk conditions have been used to define and count undesirable incidents in the Norwegian avalanche rescue service. It would be beneficial to validate these results by qualitative methods and in-depth analyses of individual rescue units.

- Future studies on the quality of avalanche risk assessments in the rescue service could benefit from combinations of technically gathered spatial data and questionnaires (Hendrikx & Johnson, 2016; Hendrikx et al., 2016) to elicit the rescuers` thoughts on specifics in route selection and decision-making in rescue operations.

- It would be of benefit to clarify how dispatch routines could facilitate risk assessment activities, both from the perspective of emergency call centres and at rescue unit level.

- The concept of overcommitment could act as a common ground for rescuers and researchers in their efforts to explore and further develop interorganizational uncertainty coping strategies in mountain rescue operations. A typical follow-up study could be to conduct questionnaires and multi-variate analyses to validate and elaborate on the findings presented in Papers III and IV. Further studies could also benefit from including a wider array of rescue units.

- The risk indicators presented in this thesis were selected by a cross-paper analysis of findings, which could support long-term monitoring of risk in the avalanche rescue service. Interorganizational studies to assess the indicators against specific criteria are needed (Herrera, 2012; Thorsen & Njå, 2014).

- The organizational structure of the Norwegian rescue service is common for all land-based rescue operations. It could be of interest to evaluate findings of the systemic safety analysis (Paper V) in the context of other types of rescue operations.

- Research on mountain rescue performance requires communication and cooperation with multiple organizations and public agencies. To encourage future cross-organizational studies, it would be beneficial to establish a common portal for access to relevant data, academic guidance and dissemination of research results.

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Part 2

List of papers

This thesis comprises five papers. References to the respective papers are given by Roman numbers.

I. Lunde, A., & Tellefsen, C. (2019). Patient and rescuer safety: recommendations for dispatch and prioritization of rescue resources based on a retrospective study of Norwegian avalanche incidents 1996–2017. *Scandinavian journal of trauma, resuscitation and emergency medicine*, 27(1), 5. doi:10.1186/s13049-019-0585-7.

II. Lunde, A., & Njå, O. (2019). Rescue performance in Norwegian road related avalanche incidents. *Cold Regions Science and Technology*, Volume 165, September 2019, 102774. doi:https://doi.org/10.1016/j.coldregions.2019.04.011.

III. Lunde, A., & Braut, G. S. (2019). The Concept of Overcommitment in Rescue Operations: Some Theoretical Aspects Based on Empirical Data. *Air Medical Journal*, Article in press. doi:https://doi.org/10.1016/j.amj.2019.05.008.

IV. Lunde, A., & Braut, G. S. (2019). Overcommitment: Management in Helicopter Emergency Medical Services in Norway. *Air Medical Journal*, 38 May–June 2019(3), 168-173. doi:10.1016/j.amj.2019.03.003.

V. Lunde, A., & Njå, O. (2019). A systems thinking approach to safety in Norwegian avalanche rescue operations. Submitted to *Safety Science* on July 15, 2019.

Conference proceedings not included in this thesis:

1. Lunde, A. & Njå O. (2016). The Reliability of Norwegian Rescue Missions Following Road Related Avalanche Incidents, Modelled with Bayesian Belief Network. Paper presented at the International Snow Science Workshop 2016 (ISSW 2016), Breckenridge, CO, USA. http://arc.lib.montana.edu/snow-science/objects/ISSW16_P3.11.pdf.

2. Lunde, A. & Njå, O. (2017). A systems thinking approach to safety in Norwegian avalanche rescue operations. Paper presented at the 27th European Safety and Reliability Conference (ESREL 2017). Portoroz, Slovenia.

3. Njå, O., Lunde, A. & Braut, G. S. (2018). Crisis management and the issue of resilience in a system theoretic perspective. Paper presented at the Third Northern European conference on Emergency and Disaster Studies, NEEDS conference 2018, Amsterdam, the Netherlands.

Paper I

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Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine

ORIGINAL RESEARCH

Open Access

Patient and rescuer safety: recommendations for dispatch and prioritization of rescue resources based on a retrospective study of Norwegian avalanche incidents 1996–2017

Albert Lunde[1*] and Christen Tellefsen[2]

Abstract

Background: Avalanche emergency response should address current accident scenarios to optimize survival chances of victims and to keep rescuers safe. The purpose of this article is to present a basis for evaluation and necessary adjustments in dispatch, prioritization, and management of Norwegian avalanche rescue operations.

Methods: This is the first peer-reviewed retrospective study of all Norwegian avalanche incidents registered by the two Joint Rescue Co-ordination Centers (JRCCs) in the period 1996–2017 that describes the characteristics and trends of rescue missions and victims.

Results: The Norwegian JRCCs have registered 720 snow avalanche events, with a total of 568 avalanche victims, of which 120 (21%) died. Including those fatally injured, a total of 313 avalanche victims in 209 accidents were treated as patients (55%), and we saw > 1 patient in 24% of these operations. Norwegian avalanche victims were partially or completely recovered prior to the arrival of rescuers in 75% ($n = 117$) of all rescue operations. In the remaining 25% of cases, the rescue service located 62% ($n = 55$) of the avalanche victims visually or electronically. In 50% of the 720 incidents, rescuers spent time searching in avalanches with no victims.

Conclusions: This survey indicates that we have experienced a shift in Norwegian avalanche rescue: from search for missing persons in the avalanche debris to immediate medical care of already-located patients. The findings suggest that a stronger focus on both patient and rescuer safety is necessary. The patients must be ensured the right treatment at the right place at the right time and the allocation of rescue resources must reflect a need to reduce exposure in avalanche terrain, especially in cases with no affirmed victims. We present a flowchart with a recommended rescue response to avalanche accidents in Norway.

Keywords: Snow avalanche, Accidents, Rescue operations, Patient safety, Rescuer safety, Risk management, Dispatch, Rescue resources

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Background

Norway's National Guidelines for Avalanche Rescue [1] give directions for the management of avalanche rescue operations. The main aim is safe and efficient rescue efforts and the rescue service work to ensure that avalanche victims receive as early and advanced emergency medical treatment as other patients in the country [2, 3]. The existing guidelines state that rescue dogs and volunteer rescue specialists be summoned and dispatched along with the first responding National Air Ambulance Service (NAAS) [4]. This routine normally causes a delay in air rescue response because the specialized resources are not stationed at the helicopter base.

It is important to customize the avalanche rescue response to the avalanche victims' need for medical assistance, the capacity of the air rescue services [5], and the safety of rescuers. Mair et al. [6] concluded that: "Medical emergencies are encountered at avalanche scenes twice as often as there is need to search for totally buried victims, clearly supporting the immediate dispatch of medical crewmembers to the accident site". The important parameters are the patients' expected survival time and the rescue time (time from the accident until treatment is initiated), given by the patients' injuries and the emergency preparedness of the rescue service. Although asphyxia is the main cause of death in avalanche victims, several studies underline that many victims die because of mechanical injuries [7–9], especially to the chest and head. This is also the case for patients who are not totally buried [7, 10, 11]. Hermann Brügger directs attention to a lack of consideration of trauma in the field management algorithm for the care of avalanche victims [12]; this should be reflected also in dispatch routines. Avalanche emergency preparedness has improved with standardized avalanche rescue training for all Norwegian air rescue crews [5] and the provision of electronic search devices (transceivers and RECCO) to all air ambulance and rescue helicopter bases. Avalanche rescue methodology, which was formerly a domain of the volunteer rescue organizations, is now a part of standard operating procedures for all actors in the rescue service [1] and Helicopter Emergency Medical Service.

In this study, we present a basis for evaluating dispatch and prioritization of avalanche rescue resources. The data describe important characteristics of rescue operations, victims, location methods, and the situation at the accident site when rescuers arrive.

Methodology

Data selection

To evaluate Norwegian avalanche rescue operations, the JRCCs authorized the first author to collect and organize data from rescue logs and reports since 1996. The National Police Directorate has granted access to police rescue logs for the same period. Eighty-three avalanche rescue variables were extracted from operational data and text fields, anonymized, and recorded in a Microsoft Excel database, hereafter named the Norwegian Avalanche Rescue Database. The variables describe time and place, incident type, avalanche size, victims, rescue resources, rescue response time, location methods, weather, regional avalanche danger level, and risk level [13, 14].

The incidents comprise all outdoor activity categories and infrastructure-related avalanches. We included all or a selection of the incidents in the study, based on type, amount, and quality of information linked to each incident (Fig. 1), thus, the number of incidents and observations will vary between analyses. As appropriate, five Swedish and Finnish incidents that were assisted by the Norwegian Rescue Service, were excluded in all analyses concerning characteristics of avalanches, victims, and patients. We concentrated specific analyses on accidents with confirmed victims in the two 10-year periods from 1998 to 2017 ($n = 268$). When describing the situation at the accident site when the rescuers arrived, we selected all cases with available relevant information in the time period 2010–2017 ($n = 117$).

Definitions

An avalanche incident is any recorded event, with or without confirmed avalanche victims. 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. All victims with any degree of physical injury were defined as patients. Data about sensitive and detailed information about the patients' conditions has not been recorded. Hence, degree of injury was defined in accordance with common practice in road traffic accidents; *"slight injury"* (treated on site or at a local doctor's office), *"serious injury"* (evacuated to a hospital for examination and treatment) and *"fatal injury"*. Fatalities were recorded without reference to length of hospitalization following the accident.

Statistical analysis

We used Microsoft Excel Data analysis with XLSTAT [15] for statistical analyses. To characterize rescue operations, avalanche victims, patients and fatalities, we calculated frequencies, rates, mean, median, interquartile range, range and 95% confidence interval (indicated by ±). Indications of monotonic trends over time were analyzed using the Mann-Kendall trend test [16, 17] and the Kolmogorov-Smirnov test [18] was applied to detect similarities of distributions. The two-Sample t-test was used to

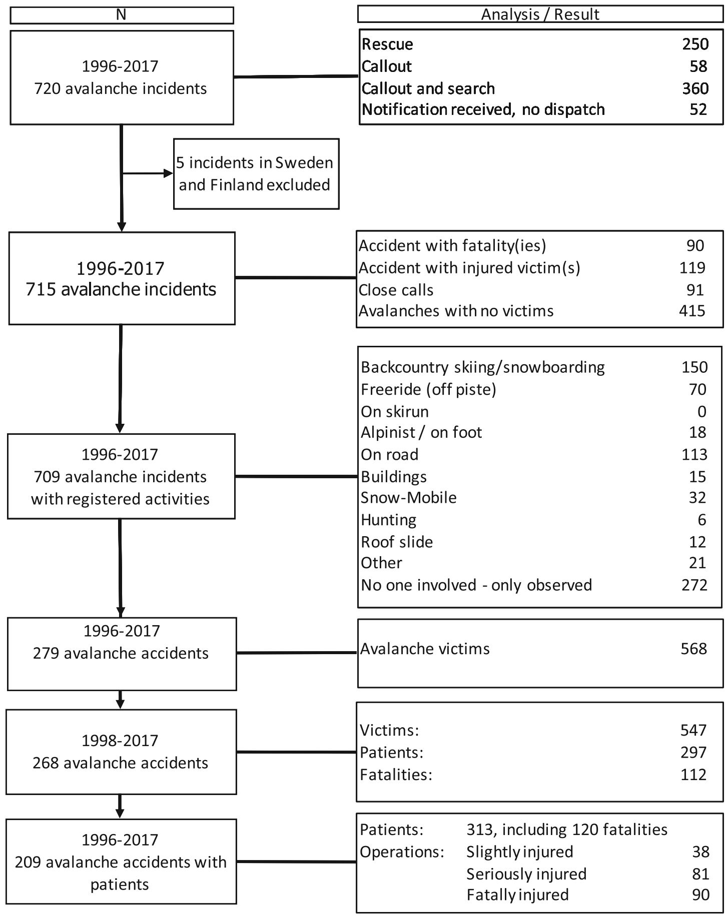

Fig. 1 Norwegian avalanche incidents 1996–2017. Flowchart showing selections of Norwegian avalanche incidents and key results, based on logs from the Norwegian Joint Rescue Coordination Centers for northern and southern Norway 1996–2017

compare group means when comparing two different time periods. We considered bilateral p values below 0.05 significant.

Results

Avalanche rescue operations, victims, patients and fatalities

In the period 1996–2017, the JRCCs in Norway registered a total of 720 snow avalanche incidents, with an annual mean of 33 ± 7 (Fig. 1). Apart from non-involvements (38%, $n = 709$), the most frequent avalanche incidents were related to backcountry skiing (21%) and roads (16%). In 360 of the 720 incidents, rescuers were called out and searched in avalanches without any involved victims. A rescue response in avalanche accidents was the case in 35% of all incidents. In the remaining 15% of incidents, rescuers were dispatched, but not activated on site.

There were 568 avalanche victims in 279 accidents. Of the recorded incidents, 58% ($n = 715$) had no victims and 13% were close calls, leaving 209 (29%) personal injury and fatal accidents. These accidents comprised 313 patients, including 120 fatalities.

Figure 2 illustrates the time series 1996–2017, based on the number of rescue operations, avalanche victims, registered patients, and fatalities. The distributions of victims vs. patients and patients vs. fatalities were significantly different, with p values 0.017 and < 0.0001, respectively. Comparing victims and patients in 1996–2007 and 2008–2017,

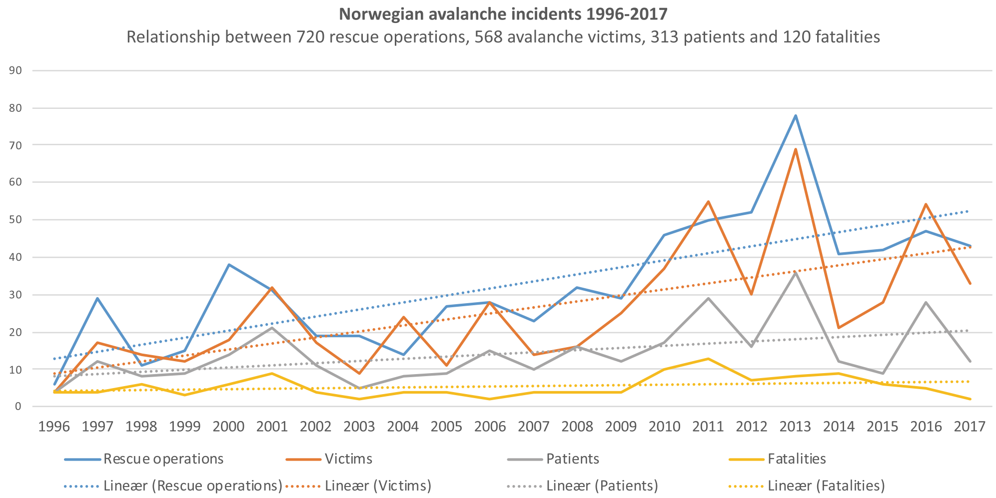

Fig. 2 Norwegian avalanche rescue statistics 1996–2017. Relationships among 720 Norwegian avalanche rescue operations, 568 avalanche victims, 313 patients and 120 fatalities in the 22-year-period from 1996 to 2017, based on JRCC information

only the last time period showed significantly different distributions (*p* value: 0.041).

We found statistically significant increases in the number of rescue operations, victims, and patients, as all these parameters nearly doubled in the period 2008–2017 compared with 1998–2007. No significant difference was found between the mean numbers of avalanche fatalities in the two time periods 1998–2007 and 2008–2017, although the annual average increased from 4.4 to 6.9.

The period from 1998 to 2017 showed 0.55 patients per avalanche victim. The trend tests showed a slight, though significant, decrease in the ratio of patients to victims (p value = 0.009, Sen's slope: − 0.013). We also noted a significant decrease in the number of fatalities per victim (p value = 0.027, Sen's slope: − 0.01). There was no trend in the series of fatalities per patients, with a ratio of 0.38.

Avalanche fatalities

The number of fatalities in avalanche accidents showed an average of 5.5 deaths per year over the period 1996–2017. The overall mortality rate of avalanche victims in the same period was 0.21 (n = 568). From 2010, we observed a marked change from the preceding 14-year annual average of 4.3 avalanche-related deaths. From 2010 through 2017, the annual average nearly doubled, to 7.5 fatalities per year (p value = 0.032). The number of fatalities fluctuated over shorter time periods: the number of deaths declined from an annual average of 8.0 fatalities from 2012 through 2014 to 4.3 from 2015 through 2017 (p value = 0.071).

Specific mention should be made regarding people falling off breaking cornices, as they are counted as avalanche accidents in Norway. This event caused 11 fatalities and 3 seriously injured patients in the 22-year period from 1996 to 2017. Eleven (two survivors) were located by organized rescuers and only three by companions. Nine were found because of visible parts, three by transceivers, and two by probing. Six of these victims were foreign citizens.

What is the situation at the accident site on arrival of rescuers?

Multiple victims and patients

The most frequent scenarios of the 209 rescue operations with patients to assist during 1996–2017 were seriously injured patients (81) and fatalities (90), with fewer (38) for slightly injured people. The average number of patients per rescue operation was 1.5 (range: 7), with > 1 patient in 24% of operations. There was a small but not significant (nsd) increase in the frequency of rescue operations with ≥3 avalanche victims to assist, from 17.9% of all operations during 1998–2007 (n = 95) to 21.3% during 2008–2017 (n = 174). Likewise, for ≥3 patients, from 6.3 to 10.3% (nsd) of all rescue operations.

Situation on arrival of rescuers

Overall, during 1996–2017, NAAS helicopters and Air-Force-operated search-and-rescue helicopters (330 Squadron) responded to 325 and 184 of the 720 registered avalanche incidents, respectively. NAAS personnel were the most frequent first organized rescue responders (26.8%, $n = 440$). They brought rescue dogs or avalanche rescue specialists to 37 and 24 of these 118 rescues, respectively. The median response time (time from the emergency call to first arrival) was 40 min (IQR: 30.5, $n = 191$). The rescue time (time from accident until the patient is offered first aid) may be much longer because of difficult access, search, or extrication. In this dataset, rescue time was only recorded in 62 accidents, with a median time of 85 min (IQR: 123.8).

Table 1 illustrates that the most common situation facing first responding rescuers in the period 2010–2017 ($n = 117$) was already-localized and more or less extricated (75.2%) and injured (82.9%) victims.

In 29 accidents, 55 victims still had to be located by arriving rescuers. Thirty-nine of these victims died (70.9%). Thirty-four (62%) were located without specialized search resources (dogs and divers) or increased manpower for efficient probing and digging (Table 2). The high number of victims located by digging was caused by avalanches hitting buildings in Svalbard in 2015.

Avalanche victims and their rescuers

Sufficient information allowed categorization of rescue strategies (self-rescue, companion rescue and organized rescue) for 416 of the 568 avalanche victims in the period 1996–2017. These categories include all kinds of activities and rescue situations, irrespective of degree of burial and need of assistance. The largest proportion comprised those who ended up on the surface or who managed to free themselves from the avalanche debris (35.6%, $n = 148$). In companion rescue situations (29.3%, $n = 122$), 86.1% of the victims survived, whereas the proportion of survivors who had to wait for organized rescuers (35.1%, $n = 146$) was 41.1%.

Methods of locating avalanche victims

Between 2008 and 2017 ($n = 316$), 89% of victims (visible avalanche victims [75.4%], those located by transceivers [12.3%], and those who were able to call for help [1.3%]) did not require specialized search resources to be located (Fig. 3). In practice, probing and search dogs are equally successful (in 3.5 and 2.2% of cases, respectively), though probing by companions is also included in this dataset.

The proportion of avalanche victims found by visual searching increased slightly between 2008 and 2017, from 68.3 to 75.4% (p value: 0.004). The major difference between the periods 1998–2007 and 2008–2017, however, is the increase in the number of avalanche victims who were located using transceivers, from 5.8 to 12.3% (p value < 0.001).

Discussion

The observed increase in the number of rescue operations, victims, and patients places an extra burden on both health and rescue resources. The high number of rescue operations with no victims requires specific attention because rescuers already spend ample time in avalanche runout zones in real rescue situations [14, 19]. Mair et al. [6] recommend a limited response in cases where witnesses cannot give clear information about victim involvement. We should develop better systems to handle uncertainty in the first phase of avalanche rescue operations.

In this study, every second avalanche victim was a patient, which approximates the findings of Hohlrieder et al. [20], which showed 49 injuries in 105 victims. Avalanche victims are exposed to considerable mechanical pressure [21] and forceful impacts with terrain features. The entire range of mechanical injuries is possible [22] and victims may sustain permanent impairment. In Canada, "trauma accounted for more than half of the deaths among people extricated in the first 10 minutes" [23] and other studies also direct attention to injured avalanche victims [6, 8, 24]. Survivors are frequently exposed to low temperatures, wind, and moisture, which all contribute to lower core temperature and an increased tendency to bleeding [25]. Therefore, early and proficient medical treatment of avalanche victims is important.

It is worrying that multiple victim scenarios are so common. In a recent study by Kottmann et al. [26], 32% of all rescue operations had more than one casualty.

Table 1 Norwegian avalanche accidents 2010–2017

	Fatal accident	Injured victims	Close call	Total	%
Not localized	22	6	1	29	24.8
Localized-not excavated	1	3	2	6	5.1
Localized and excavated	16	49	17	82	70.1
Total	39	58	20	117	
%	33.3	49.6	17.1		

Situation at the scene of the accident on arrival of rescuers, relative to type of accident. $N = 117$

Table 2 Rescuers' methods of locating 55 victims in 29 Norwegian avalanche accidents of all categories in the period 2010–2017

Location method	Visible	Probing	Dog	Transceiver	Diving	Audible	Digging
N	17	5	6	14	1	2	9
%	30.9	9.1	10.9	25.5	1.8	3.6	16.4

This phenomenon should be addressed in both emergency response and accident prevention.

The downward trends in numbers of patients and fatalities per victim may reflect an increase in successful rescues, which results from both swift victim location, use of safety equipment, and successful prehospital patient care. The ratio of patients per avalanche victim indicates victim vulnerability. Equipment like transceivers, probes and shovels contributes to reduced burial time, and backpacks with floatation devices may prevent victims from being totally covered by debris [27, 28]. However, none of these offer any direct or extensive protection. Safety helmets are recommended for recreational skiers and snowboarders [29] and "should be considered when travelling in avalanche terrain" [22]. The important message for dispatch centers is that avalanche victims wearing safety equipment will likely be found and excavated before the arrival of rescuers, and they are probably injured.

The varying ratio between avalanche victims and the number of fatalities emphasizes that coincidence rules the outcome of these accidents. Those who end up totally covered by avalanche debris are dependent on rescue-competent companions to increase their likelihood of survival. This study indicates that mountain travelers are increasingly aware of their rescue responsibility because more avalanche victims have been located visually and by using transceivers. Consequently, it is unusual for the Norwegian rescue service to have to search for missing people in avalanches. If so, the victims are often visible or searchable with transceivers or RECCO.

The length of burial time and burial depth affect survival rate [7]. This connection has rightly guided development of emergency preparedness and rescue response for years. The parallel introduction of more efficient means of companion rescue has caused a change in the initial tasks of the first responding organized rescuers [30]. We should adjust the allocation of rescue resources to reflect current rescue scenarios and ensure that patients get the right treatment at the right place at the right time [31]. Avalanche accidents must be perceived and handled as acute medical emergencies. This is reflected in today's emergency preparedness system, as air ambulance helicopters are frequent first organized rescue responders. However, if we aim to save the most critically-injured patients, prehospital medical personnel should respond without first waiting or detouring for voluntary search resources. In most cases, teaming up with extra medical personnel may be more pertinent than fetching manpower and dogs for searching. The findings of this study, and the conclusions of Mair et al. [6], provide the basis for a flowchart (Fig. 4) for dispatching and prioritizing resources in avalanche rescue operations in Norway.

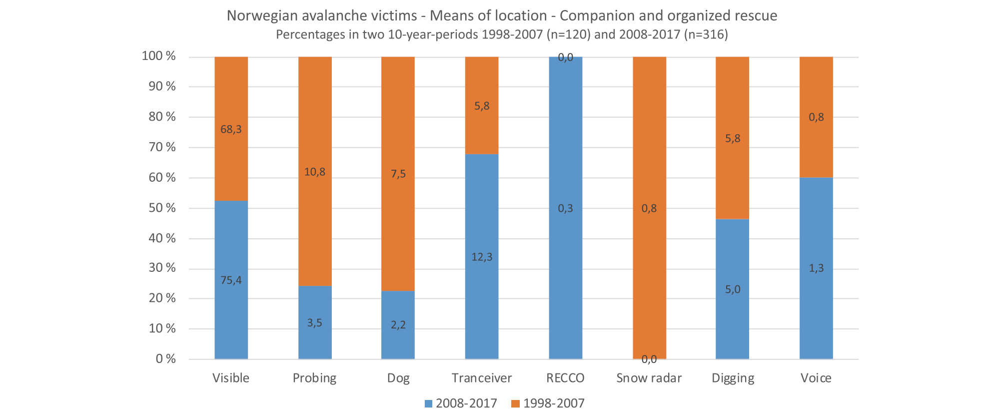

Fig. 3 Methods of locating avalanche victims in Norway over two time periods; 1998–2007 and 2008–2017

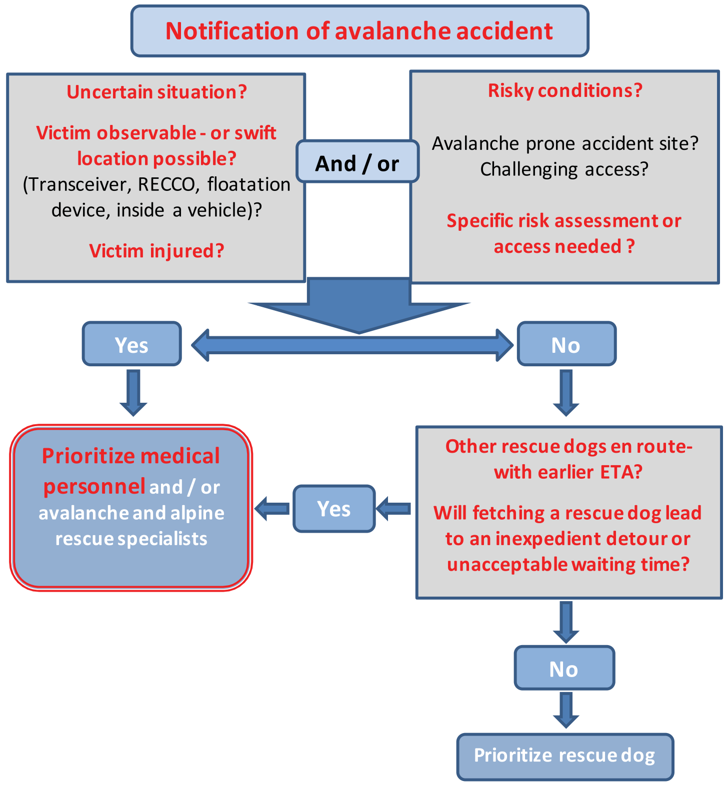

Fig. 4 Flowchart showing the recommended rescue response to avalanche accidents in Norway

Limitations

Our Excel database was 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 still varies because of both inter-operator differences in registration of relevant details and inter-regional differences in conducting and documenting rescue activities. To compensate for a lack of information in logs and reports from relevant authorities, we have also included reports from the mass media. In some cases, both rescuers and involved victims have been asked to supply relevant details. Nevertheless, some parameters suffer from varied levels of registration detail, which causes a bias in evaluation of time series and trends, especially in cases without fatalities or injured persons.

Conclusion

We have experienced a shift in Norwegian avalanche rescue from searching for missing persons in the avalanche debris to providing immediate medical care of already-located patients. Subsequently, the rescue service's longstanding focus on rapid implementation of effective search operations should be changed to speedy and safe provision of advanced prehospital emergency medical treatment and evacuation.

Dispatch routines should reflect that many rescue operations take place in adverse conditions that threaten rescuer safety. Especially in situations of uncertainty about victim involvement, necessary actions to remain in control of the situation should be taken on all managerial levels, even if this means a slower and more limited rescue response.

Abbreviations

IQR: Interquartile range; JRCC: Joint Rescue Coordination Centers in South and North Norway; NAAS: National Air Ambulance Service; RECCO: A two-part system comprising a detector used by organized rescue groups and reflectors that are integrated in mountain travelers' clothes or gear

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Availability of data and materials
The datasets used and analyzed during the current study will in due time become available at the JRCC South-Norway on reasonable request.

Authors' contributions
AL collected the data, conceived and designed the study, performed the statistical analyses, interpreted the data, wrote and revised the manuscript. CT contributed to the development of the flow chart. Both authors read and approved the final manuscript.

Author information
AL has worked as a police officer since 1987 and is currently employed by the University of Stavanger as a PhD candidate. AL was a delegate for the Norwegian Red Cross Rescue Corps to the International Commission for Alpine Rescue (ICAR), Avalanche commission, from 1996 to 2015. CT is a trained electrical engineer and nurse and has worked as a Helicopter Emergency Medical Service rescue paramedic since 2001. Both authors are members of volunteer mountain rescue teams and former avalanche dog handlers.

Ethics approval and consent to participate
AL was granted access to data by the Joint Rescue Co-ordination Centers and from the National Police Directorate of Norway. Only AL had direct access to the JRCC and police rescue logs, reports, and the subsequent Excel database.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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Paper II

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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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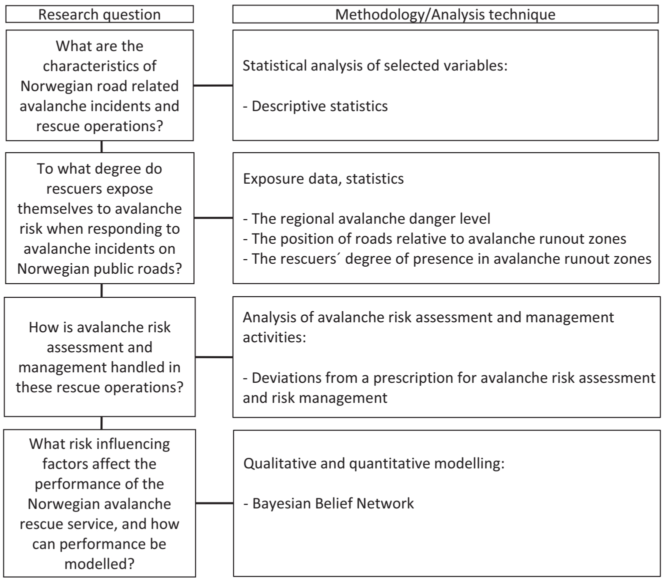

Fig. 1. Research questions and related analyses.

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

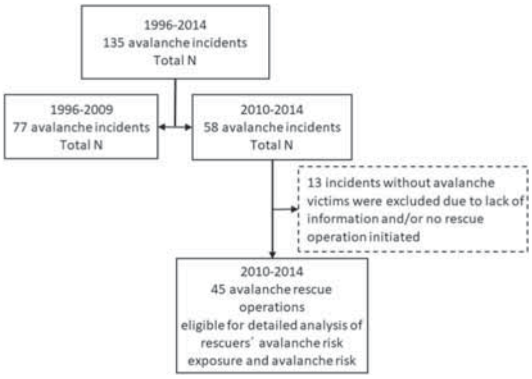

Fig. 2. Flowchart showing the selection of Norwegian road related avalanche incidents included in the study.

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.)

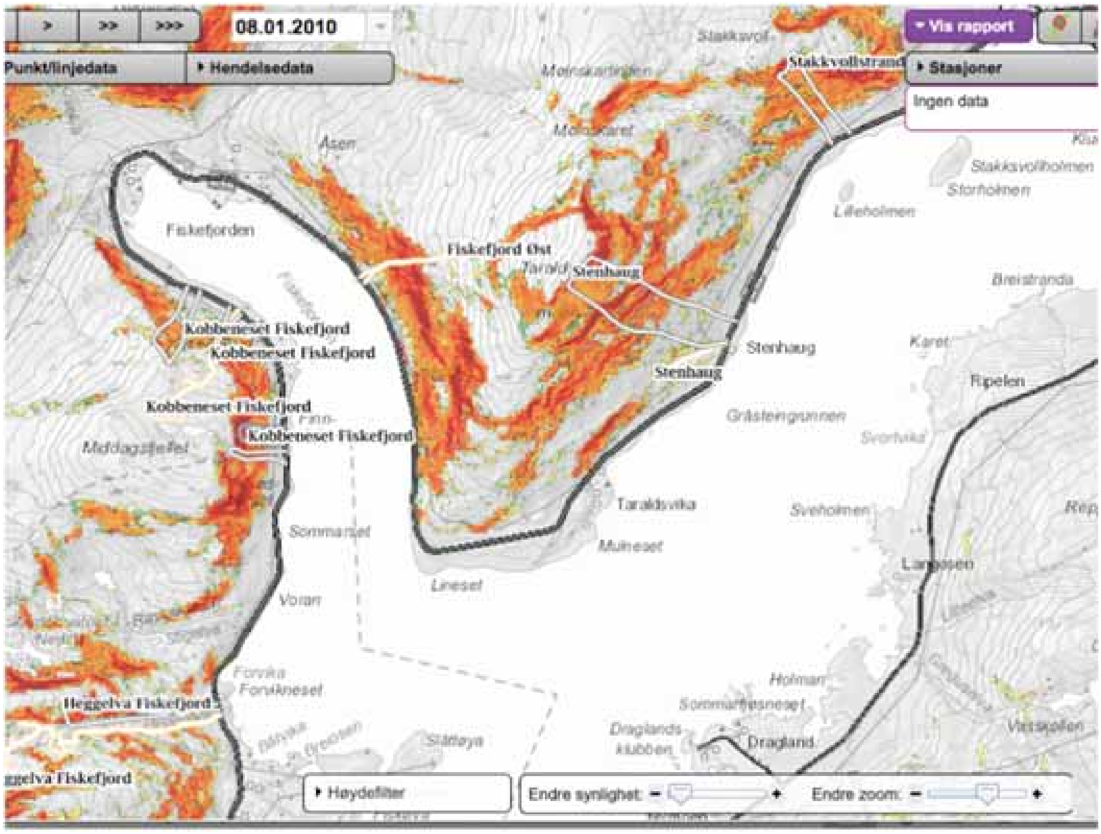

Fig. 4. Example: Screenshot from www.xgeo.no, showing historical avalanche paths (white and yellow delineated polygons) reaching the road in the same area as shown in Figure 3 (Lødingen, Nordland, North-Norway). (For interpretation of the references to colour in this figure legend, the reader is referred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

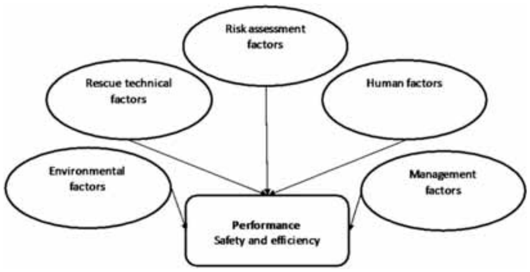

Fig. 5. Generic Bayesian Belief Network. A generic BBN model with factors that may affect performance (safety and efficiency) in the Norwegian avalanche rescue service.

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 ($\chi2 = 281.337$, $p = .77$), 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.

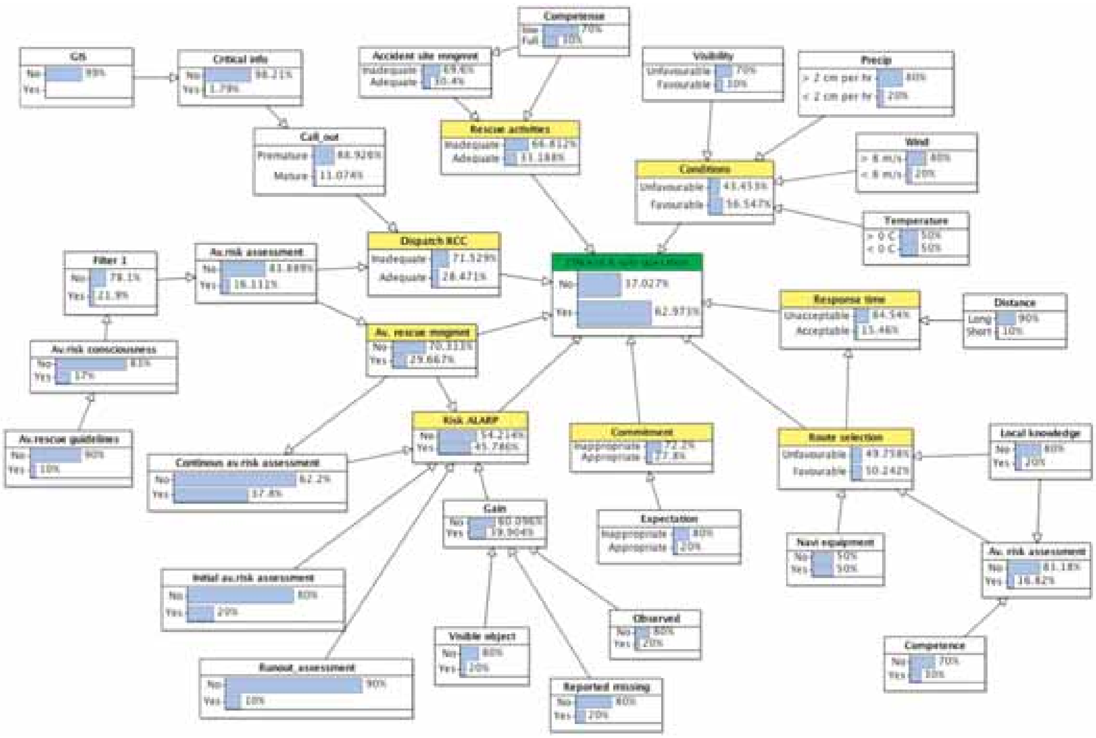

Fig. 6. BBN model of the performance of the Norwegian avalanche rescue service during road related incidents, in a normal state with apriori probability values.

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,

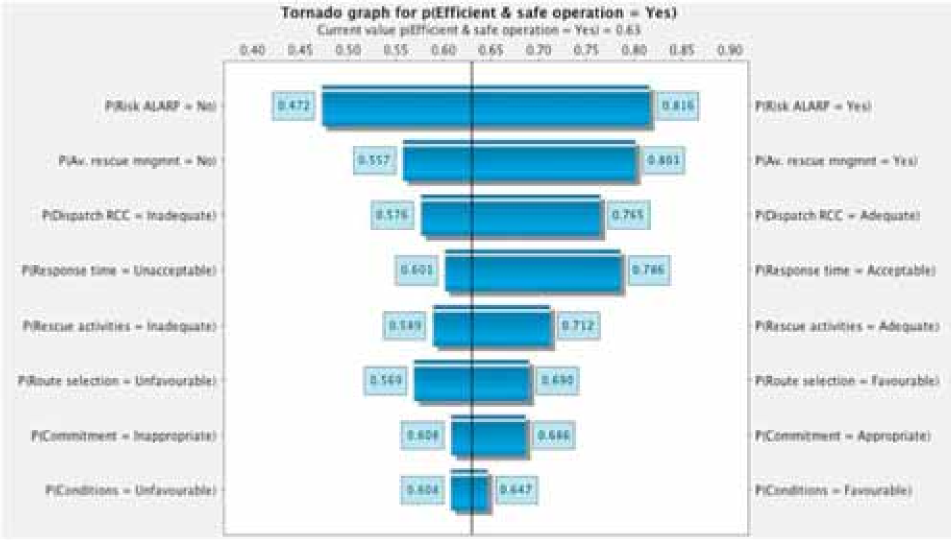

Fig. 7. Sensitivity analysis. Variables of greatest influence are indicated by the length of the horizontal bars. The vertical line indicates the marginal probability for an efficient and safe operation (0.63).

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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Paper III

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Original Research

The Concept of Overcommitment in Rescue Operations: Some Theoretical Aspects Based on Empirical Data

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A B S T R A C T

Objective: Studies on Norwegian avalanche rescue operations have indicated high-stake searching of avalanches during elevated risk conditions. We perceive these characteristics as a sign of overcommitment. The purpose of this study is to explore the concept of overcommitment in Norwegian medical evacuation and rescue operations. How can overcommitment be described and understood as a uniform concept in rescue operations based on empirical data?

Methods: In a qualitative, exploratory study, 9 focus group interviews were conducted with a total of 30 crewmembers from the Norwegian air ambulance service.

Results: In this first in a series of 2 articles, crewmembers' reflections on the concept of overcommitment, important factors to consider when balancing risk and benefit in every mission, and a number of causal factors are presented. A definition of overcommitment in the context of rescue activities is presented.

Conclusion: Air ambulance personnel recognize overcommitment in a variety of situations. They broaden the concept to include both regular, everyday actions and hazardous rescue attempts in extraordinary incidents. The causal factors form recognizable constellations that may offer useful starting points for systems-based counteracting measures. The definition of overcommitment could provide a background for evaluation and learning in the rescue service.

In a previous study on Norwegian road-related avalanche rescue operations, it was concluded that "human factors in avalanche rescue, like the roles of expectation, motivation and commitment, need further clarification."[1] The study indicated high-stake searching of avalanches during elevated risk conditions in poor visibility and often with little information to justify the scale of rescue operations. These characteristics can be regarded as a sign of overcommitment. As a general concept, overcommitment in rescue operations has not been thoroughly approached in previous research. Implementing an intensive effort in a critical situation is in general regarded as a positive valued virtue; thus, doing more than expected is difficult to question, challenge, or criticize. Ash and Smallman[2] studied the conflicting imperatives of fulfilling a rescue mission and keeping rescuers safe in dynamic risk situations, claiming that rescue organizations are facing an increasing challenge of overcommitment. Basing their judgment of overcommitment on the definition of "rescue attempts in circumstances that were judged too risky to personnel by the expert cohort,"[2] their main focus was the subject's choice of tactical mode, offensive or defensive, in various demanding emergency situations.

In conditions of high avalanche danger, rescuers need to make careful judgments about their own safety,[3] which may not seem appropriate to bystanders or relatives of the victims. In these situations, private parties may initiate rescue activities rather than wait for an official rescue operation. A recent example is the tragic snow avalanche accident on November 22, 2017, in Anchorage, AK, in which friends and family recovered an avalanche victim while rescuers were awaiting safer and more favorable conditions.[4] Further exacerbating the pressure on the individual rescuer in public emergency services is the duty to treat.[5,6] Myhrer[7] stated about Norwegian police officers that the statutory obligation to act is not unconditional but rests on a pyramid of necessary and legal factors. A pertinent question is whether rescuers can be allowed on their own initiative to take on a mission that is considered too risky by normal standards because rescue personnel are by law obliged to engage in safe work practices.[8] On the other hand, the responsibility to assess and act related to available risk information is placed on the actors in the sharp end.

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They are not passive instruments acting in accordance with orders from a command center. Thus, what should be regarded as according to "normal standard" is highly contextual. It is difficult to formulate in detail in standing operational procedures. It is also closely related to the competence and previous experiences of the involved personnel. Risk acceptance criteria are not strictly defined in Norwegian land-based rescue operations or in absolute values or plain words, although one may assume that the risk shall be kept "as low as reasonably practicable."[9]

Norwegian helicopter emergency medical service (HEMS) personnel are frequent first responders in both prehospital medical emergency and search and rescue missions.[10] HEMS operations to provide immediate health care to critically ill and injured patients in uncertain situations and austere environments are stressful events[11,12] that may challenge the crewmembers' ability to balance the needs of patients and mission safety. Their operational decisions will directly affect their own vulnerability, sometimes to the extent that they suffer personal injuries and death.[13] Although most emergency response organizations would support the recommendation of Blancher et al[3] that "safety of the rescuers is the highest priority," the commitment of altruistic and solution-oriented rescuers may override this principle.[14]

We wanted to explore the concept of overcommitment in Norwegian medical evacuation and rescue operations and based our study on the following research questions:

1. How can overcommitment be defined in the context of medical emergency and rescue operations?
2. Is overcommitment recognized as a phenomenon in Norwegian medical evacuation and rescue operations?
3. What are the characteristics of overcommitment in Norwegian rescue operations?
4. How is overcommitment identified by professional rescuers during real operations?

First, we explain how HEMS personnel contributed in data collection and concept development. Then, we present the empirical data before theorizing about working principles, comprehensions, and causal factors related to the degree of commitment in rescue operations.

Methods and Materials

In this study, we interviewed HEMS personnel from the National Air Ambulance Services of Norway about the concept of overcommitment and what they do to counteract unwanted exposure to high risk in rescue operations.

Selection

The National Air Ambulance Services of Norway operates 12 helicopter bases around the country, all with a 24/7 on base readiness for crewmembers. In 2016, they performed a total of 7,796 missions.[15] The helicopters are staffed with 3 crewmembers: a pilot, an HEMS rescue paramedic, and an emergency doctor. The helicopter crews operate autonomously on request from emergency medical communication centers. The Governor of Svalbard operates 2 air rescue helicopters with a 5-man crew responsible for sea and land rescue in the Artic north. Although the mainland HEMS and the air rescue helicopters on Svalbard are 2 different concepts, the crew members face similar challenges in sorting out the risk level and necessity of rescue missions.

Research Design

In this qualitative study, we explored how highly experienced prehospital personnel recognize and handle overcommitment. The interviewees were selected by way of convenience sampling[16] after positive feedback to interview on-duty crews. Bases were selected by location, and crewmembers were selected by random because they happened to be on duty on days requested to perform focus group interviews. All crewmembers were informed that participation was voluntary, and no one refused to take part.

Malterud et al[17] presented a model for the assessment of sample size in qualitative studies in which information power is given by aim, sample specificity, theoretical foundation, dialogue quality, and analysis strategy. An exploratory study normally requires a large sample to counteract an imbalanced collection of relevant phenomena. This sample was chosen on the grounds of their unique experience in handling dangerous missions, allowing a smaller number of cases. We expected that the characteristic phenomena of overcommitment would find support in safety theory, effectively reducing the need for a large sample. The dialogue was marked by the fact that participants and moderators shared a common background from the emergency services and medicine, quickly establishing a trustful rapport. A cross-case strategy of analysis was a natural choice to "produce new knowledge and augment existing knowledge and experience."[18] Malterud et al[17] state that "cross-case analysis requires more participants to offer sufficient information power . . .," but too many participants would complicate the analysis.

The first author, moderating the interviews, has been a member of volunteer mountain rescue organizations for 40 years and has served as a police officer for nearly 30 years. In these positions, he frequently cooperates with air ambulance crews. This implies that he is acquainted with some of the interviewees and has taken part in some of the rescue operations mentioned during interviews. The second author, a medical doctor and professor in risk management and societal safety, observed 1 of the interviews and took part in planning the study and analysis of the data.

Material

Nine crews, altogether 30 crewmembers, were interviewed in the period from March 2017 until April 2018. The crews were stationed at 5 bases run by 2 different HEMS providers in North and South Norway. The HEMS doctors were linked to 4 regional health authorities (in-hospital service as anesthesiologists). Some interviewees had recent experience from Air Force−operated search and rescue helicopters, ambulance service, and commercial helicopter companies. The study was based on informed consent from each single participant. Each interview lasted 60 to 90 minutes. The interviewees were 3 women and 27 men aged between 30 and 60 years, with a mean age of 45 years. The mean length of experience from this service was 10 years, ranging from 0.5 to 34 years. In addition, all crewmembers upheld considerable professional experience from their previous employments.

All interviews except the first were tape-recorded to support transcription and summary. The material was transcribed immediately after the interviews, and the electronic sound files were deleted. Thus, no electronic material revealing voices or individual expressions that can be used for identifying respondents or tracing answers back to single individuals were stored. Therefore, there was no need for approval according to former data protection legislation or consultations in accordance with the new regulations of 2016/2018.

The written reports from these focus group interviews resembled police interview reports in that short summaries were given in combination with full transcriptions. To a large extent, linguistic pause fillers and formulaic language were omitted unless they clearly conveyed meaning to the sentence. All reports were anonymized with regard to place names and recognizable events. After write-up, the reports were sent to the individual interviewees for comments and validation, in line with Prudence Plummer-D'Amato's member checking,[19] to enhance credibility and trustworthiness. All reports were approved without corrective comments.

The interviews followed a common structure with an initial presentation of the background for the study followed by a clarification of specific concepts and practical considerations. The interview guide contained 5 main themes: 1) associations with the concept of overcommitment, 2) recognition and sharing of operational cues, 3) causal factors in overcommitment, 4) preventive factors in overcommitment, and 5) overcommitment and learning. To support the exploratory nature of the study, we did not apply strict limitations to the topics and discussions that arose from introducing the main themes.

The interviews were exported to the software program QSR International NVIVO 11 (QSR International, Melbourne, Australia) to aid the necessary steps of systematic text condensation.[20] Starting from the original themes of the interview guide, main categories and meaningful key words emerged from the supplied answers and comments.

Results

The first part of this section concerns the crewmembers' thoughts on the concept of overcommitment and how they seek optimization by balancing rescuer and patient safety. The last part is a presentation of what they see as possible phenomena and situations that may lead to overcommitment.

The Concept of Overcommitment

Cost-Benefit Considerations

The term *cost benefit* was frequently used to indicate the considerations that crewmembers strived to make during rescue missions. In this context, cost is an undefined measure of life-threatening "risk," whereas benefit reflects the patient's prognosis given the assistance from air ambulance personnel. We identified four important elements of the Cost-Benefit considerations: Patient Situation; Rescue Situation; Triage and Rescuer Robustness. In the following sections, the interviewees are referred to by an uppercase letter and a number (eg, A1).

Patient Situation

Interviewee E2 pointed at communication about the patient's condition. "Can this patient wait until day light, or is it urgent to respond ASAP? That's . . . I think . . . the key to everyone having the same SA (situational awareness) . . . " C3 commented, "I have a small rating inside my head on how important it is that this is an air ambulance mission. Is it crucially important that we arrive right away, or will it be of significant benefit to the patient, or is it almost so that we will see if we will be of any use to the patient, at all. A mission is not just a mission." G2 commented to G3, "You are good at this. You use one tool when you think that we need to think twice about a nightly mission in poor weather conditions. Then, you present facts about the patient. Listen, this patient will actually do very well without us." G3 responded, "But that is a very important point to bring forward, I think. One has to consider the medical benefit of the mission." G3 later concluded that ''As such, this is associated with risk, but if we can minimize the risk when it has no effect, then it makes sense, I think.''

Rescue Situation

The interviewees do not accept, by principle, to risk their own life to save a patient`s life. F3 stated, "No, we are all going to go home. None of us are going to die at work. Then, rather, the patient will have to die. And, I mean it. I am really not willing to sacrifice my own life . . . however, to a certain extent, we do that, anyway . . ." G2 presented a mountain rescue case in which they tried to land near a patient with a broken ankle when surprised by a serious down draft that nearly grounded the aircraft. "In retrospect, we staked incredibly much compared to the benefit." G3 added, "That ankle is not worth risking three other lives, because you can just go back and get him the following day."

Triage

Interviewee J3 compared overcommitment with "analogous concepts in medicine that we call over-triage or over-consumption of resources." He then presented the medical epidemiological expression numbers needed to treat and numbers needed to harm[21] as possible measures of necessity when approaching the apparent mismatch of high-risk−low-gain rescue operations. J3 illustrated this by saying, "If we over-expose ourselves in avalanche danger zones, we will eventually experience an accident with loss of rescue personnel." C2 underlined "but if you have something to gain, you may go an extra step, but not on all missions. Because, then you would do that all the time." G3 pointed at individual differences in judging patient needs relative to their own chances of safely reaching the patient. ''But there are differences between crews, as well. Some crews provide healthcare, while others do not. Because, in one crew the composition is such that you do not respond, while in other crews the composition is such that you do respond and complete the mission. So that's how there is actually a difference. All the time. But that, I think, is quite OK."

Rescuer Robustness

Several crews pointed at the importance of personal robustness when choosing to abstain from a dangerous mission and linked this attribute to volume training and experience from similar situations. F3 stated, ". . . when we get a little more experience from this kind of work, we are a bit more robust at standing by that choice. In fact, we must choose our own safety rather than go in and take unnecessary risk?" C2 said, ''We are used to turning back. We can go on a mission and turn around and be very pleased when we get home because we turned back—did the right thing.''

Causal Factors

The crewmembers presented a great variety of phenomena and situations that could bring them beyond the diffuse border between accepting or abstaining from a dangerous act or mission.

Personal Affection and Risk Willingness

Crewmembers pointed at individual differences in mission commitment, causing a variability that both strengthens and challenges a high-reliability organization that relies on standards and procedures. Personal affection for specific activities, like mountain climbing or diving, interacts with risk willingness to give different responses in otherwise similar missions. A1 commented, "Well, it becomes a subjective opinion of the need for us to do it." G2 added, "Everybody has some preferences, and for me it's the mountains. And then, we're actually stretching it, because it's our arena and our own people . . . " D2 linked leisure-time activities and line of work, "Those who choose this profession are also risky within a certain limit. People have a hobby, often, which includes risk." A3 commented, "Indeed, we often have a very objective goal of how to do things, right? But then this overcommitment, if that's what we call it, comes in as a subjective thing. This is what we just have to do, or I want to take on this mission."

Tunnel Vision and Target Fixation

Tunnel vision was a frequently mentioned phenomenon that could jeopardize their collective mindfulness of mission-specific risk factors. F2 said, "As for myself, it's tunnel vision. Locking one's focus on one thing." Also, the expression "target fixation" was used, both literally to describe a hazardous phenomenon when flying and in a transferred meaning in rescue operations. "We suddenly isolate ourselves from the rest of the world, inside that little time window, right there and then" (G2).

Mission Creeping

Crews further warned about "mission creeping" in which previous positive experience in similar situations and initial efforts to access the patient temped them to try harder. C2 identified it as "The negative spiral where everyone is completely set to solve the mission and pushes and pushes,'' whereas J3 described it as "Those situations where one can suddenly feel that . . . I just have to go over and have a look . . . You should really get away from that place . . . " These situations are often related to flying in marginal conditions. ''Weather-wise; on the border line, but then, it went well, and now it`s a success story'' C3 concluded about a mountain rescue mission involving 2 critically injured patients.

Lack of Knowledge

Crewmembers quite unanimously praised knowledge as a prerequisite for sound judgment of operational risk and linked it to cue recognition, risk assessments, information flow, coordination of resources, and risk communication. To commit yourself beyond your own capacity was considered just as dangerous as consciously committing beyond an identified margin of safe practice. A3 asked, "About overcommitment, is that because you don't know your own limitations or because you lack knowledge?" He found that a downside of feeling knowledgeable is overconfidence. "It may be a weakness if one comes in a situation where one believes a bit too much on one's own abilities.''

Demanding, Low-Frequency Events

Interviewees find that infrequent, demanding events increase their feeling of stress and mostly positive excitement. F3 observed, ". . . when it comes to overcommitment, I feel that the more serious things we respond to, the greater the degree of overcommitment, because that's not what we do . . . often, I think." Challenging environmental factors and elements of technical rescue techniques were mentioned as important cofactors contributing to this feeling. F3 explained the following: "But I think . . . missions that we think are . . . not fun, but, interesting, then, and which we have trained for, then I think we need to keep at the back of our head that overcommitment plays a little . . . because . . . you feel that you get a little too geared up . . ."

Low-Risk, High-Frequency Events

Air ambulance crews are frequently in routine situations with generically defined risk factors that need to be analyzed and evaluated in each and every novel situation. One example was how they accept improvised landing sites to save time. G1 commented ironically, "Yes, we'll save 20 seconds on landing, and then we'll be there waiting for the ambulance." A3 concluded, "It is a little stupid to land in the forest when there is actually an airport close by" and pointed at a need to "standardizing things a bit." G2 explained the following: "We know about a number of risk factors in our daily lives, and we are really willing to continue to take that risk because we perceive it as low."

Equipment Availability

There was no common understanding that equipment availability in a critical situation always led to increased and dangerous commitment. They pointed at nonstandard use of equipment in difficult, time-critical situations and modern equipment, like night vision goggles (NVGs) and moving maps, which allowed them to lower the weather minima for flying. A1 thought there were higher minima before without NVGs, ''but then again, we were out flying in bad weather, without NVGs, in those times . . ." Some crewmembers pointed at increased safety as a result of new equipment and a focus on crew resource management (CRM). A2 answered "No, clearly not" when asked if their judgment of a situation remains the same with or without available equipment. He used their diving suits as an example; the old suit was too buoyant for diving, the new one "opens up to take much higher risk and do things that you could not do before." In general, by their sheer arrival by helicopter, they feel an increased pressure to handle the situation, although usually being "quite good at saying STOP" (H2).

Expectations and External Pressure

Two types of expectations influence decisions to attempt a rescue effort: the crewmembers' internal motivation and a variety of expectations from victims, bystanders, legislation, and cooperating rescue units. J3 illustrated the dilemma by asking, "And that's typical; there are people there (in need of help), and then the specialized rescue service should choose not to help them?" C3 found that "You are increasingly aware of expectations, from the employer and the world around us. The fear of being held responsible, in retrospect, I think unfortunately is something that is becoming more and more applicable." The pilots seemed to be less influenced by external factors. G1 asserted, "There is no judge who can point at me and say; I think you should have (chosen to fly)." H1 stated, "If you think about expectations or pressure, we don't feel that very much," adding that they always try to find good solutions.

The strongest urge to do something in critical situations arises when "Nobody else can do it." A2 said, "The satisfaction of solving things where others are stuck. That's definitely something that makes you push it a little . . ." A2 also said that he feels "less autonomous" when other air rescue bases "are in the loop" (eg, when the mission is transferred from another crew because of flight time limits). In a recent mission, he consulted a senior member of the other crew, getting the impression that flying conditions were OK. He sensed that "we should really try to fix it." He attributed this to his respect for older colleagues and "an expectation that made him want to be a good soldier."

Victim allegiance was not considered an unambiguous risk factor in this service, although children do trigger crews to greater efforts and higher risk tolerance. B1 said that "there is a difference between a 5-year-old and a 95-year-old" but maintained that compliance with flight minima, even in those situations, was "surprisingly easy." A3 stated that flight minima remain the same, irrespective of type of emergency, and the doctors avoid stressing pilots by referring to the patient's poor condition (D3).

Postquiescence Syndrome

Some air ambulance crews reported a stronger urge to engage in a mission after long, quiet periods, resembling volunteer rescuers who may wait for months and years in between call outs. This postquiescence syndrome, named by the authors, is characterized by increased activation levels and a strong desire to complete a mission. A2 mentioned an example in which they misjudged the consequences of high altitude and overloaded the aircraft when taking on 2 mountain rescue missions in the same area. He explained the following: "There was no time pressure related to the missions, but they had had very few missions and got two missions close to each other that they would like to solve." F3 suggested, "Maybe it's that feeling that now, it is finally happening what we have trained for in such a long time."

Unforeseen Events

Although termed *unforeseen events*, the statements made by crewmembers indicate that the risk was reasonably conceivable[22] and always retrospectively explainable. Often, these situations were related to natural hazards causing retreat or unplanned landings. C2 stated, "Coincidence rules, and the weather can be unpredictable." Crews committed themselves in attempts to reach an accident site or search for missing people, later realizing that they had missed out on critical information, misinterpreted the circumstances, or found themselves in a conjunction of surprisingly adverse conditions. Overcommitment followed as a result of not allowing time to acquire sufficient information about the situation.

Organizational Overcommitment

Organizational factors were identified as sources to overcommitment in that rescue units are called out in excess numbers or activated on-site in situations of uncertainty. J3 referred to rescue operations "with spontaneously released avalanches, then there are more spontaneous avalanches, and we have seen all rescuers, all gathered in the same area . . . " Crewmembers saw it as a part of the professional attitude to have "some kind of conscious overcommitment and then de-escalate when someone gets information saying it is not necessary." C3 explained, "In search and rescue operations, it is very often uncertain, first of all, how many patients, if any, and if you have a number of people, then you do not know if there are patients or if they are stuck somewhere or missing."

In a similar category are search operations in which no one was confirmed missing. C1 referred to that as special "avalanche winter," where they regularly responded in poor weather conditions, on "things that people had only observed from the road." "There were no observations or traces of people." C2 suggested that "They . . . think that the volunteers are so seldom called out to avalanche incidents that when it's finally something, they'll be allowed to continue—as a reward."

At the other end of the scale was the extrication of confirmed dead people. J4 stated, "There is one thing that is very interesting here, and that's when you're going to bring out dead bodies, in terms of risk. And then we have seen quite a few . . . or at least heard of . . . quite a few hairy operations where they pick up . . . yes . . . people who are in "the mountain wall."

Discussion

This study is based on data from 30 respondents representing HEMS services in 4 regions of Norway. Thus, we claim that the study gives a representative picture of opinions related to the driving forces in rescue missions for personnel engaged in Norwegian HEMS services.

The reflections of air ambulance personnel broaden the concept of overcommitment to include regular, everyday actions as hazardous rescue attempts in extraordinary incidents. They point at flawed communication and unsafe control actions[23] preceding the "points of no return," placing them in hazardous conditions that may have seemed surprising at the time. Their examples draw a fine, blurry line between a necessary change of pace to reach the patient in time and impetuous actions putting their lives in danger. The following definition of overcommitment in rescue work emerges from the findings of this study: "situations in which rescuers make themselves or others vulnerable by committing more than is feasible, desirable, expected, recommended, or compellingly necessary in the given scenario and thereby run the risk of personal injury or death."

Air ambulance personnel described emergency response situations in which they deviated from flight minima to reach the patient or a hospital in time. Although describing compliance with flight regulations as "flying in a square tunnel," they obviously added flexibility to those tunnel walls. In line with their cost-benefit approach, they are occasionally willing to sacrifice some of their own safety margin to benefit the patient, even if this implies bending the rules. This seems to be in accordance with the conclusions of the Unites States National EMS Pilots Association survey that both "internal" and "external" pressure made pilots "fly in questionable weather conditions."[12] Laws and regulations are not necessarily adapted to front-end rescue activity, which makes rule bending a natural choice in situations in which rescuers face strong conflicting interests. Over time, this may become institutionalized as organizations migrate toward higher risk levels.[24]

Balancing rescuer and patient safety constitutes the core of risk management in rescue operations. Pietsch et al,[25] pointing at the dangers of mountain rescue operations, concluded that "medical tactics are dictated by those factors, and benefits and risks of medical interventions need to be carefully weighed." CRM training is mandatory for all personnel engaged in HEMS services. Discussing risk connected with single missions is an integrated part of this training. The results of CRM training, no doubt, influenced the statements made by many of the interviewees. This was especially the case when discussing how they identified overcommitment and their strategies to prevent overcommitment in HEMS operations.

Four factors summarized the crewmembers' focus on cost-benefit considerations. Even if the weighting of these factors is uncertain and ill-defined in a dynamic rescue environment, they may be used to both predict and evaluate the level of commitment in a given rescue situation. Triage will build on the information that is linked to the 2 opposing weights, patient and rescue situation, and aim at decisions about necessity, urgency, and feasibility of the mission. Optimal evaluation cannot occur until after the intersection of decisional certainty and situational uncertainty[26] (Fig. 1), a point in time that may not even be reached during an ongoing rescue operation.

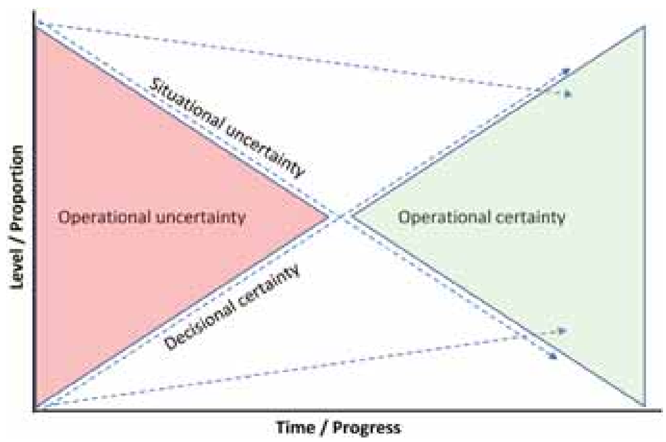

Figure 1. The role of uncertainty in cost-benefit considerations. Blue arrows indicate levels of situational uncertainty and decisional certainty. Triangles indicate the proportions of operational uncertainty/certainty over time as a rescue operation progresses from scramble until the end of operation.

This explains the fourth identified factor, rescuer robustness, because most decisions about cost-benefit will be made under uncertainty about both patient and rescuer safety. Sacrifice seems unavoidable, and satisficing[27] becomes a working principle.

One may assume that the tendency to overcommit will decrease as operational certainty increases. In view of the causal factors identified by crewmembers, certainty in operations may not be sufficient to counteract this phenomenon. Individual characteristics and considerations will still affect the perception of risk as well as the final judgments about cost and benefit in each and every new situation. Rescuers seek information or need to rely on their affective reactions.[28] In these situations, the "affect heuristic"[29] (ie, judging the risk as low and the benefits as high because they have positive feelings toward the activity) will unconsciously influence decision making.

Dealing with the specific risk issues related to every single rescue operation should be regarded as an important element of sound and prudent practice in the cross-professional group constituting the HEMS team. Even though both medical and aviation personnel have quite clear criteria for acceptable practice in their own fields, in rescue operations these criteria have to be melded together to ensure an optimization of the benefit without violating relevant safety measures in every single situation. Consciously addressing the phenomenon of "affect heuristic" during CRM training sessions may be a means for developing a sensible cross-professional safety practice in such situations. The data from this study indicate that this is done to a certain degree, but making this even more explicit might strengthen the cross-professional craftsmanship related to case-specific risk assessments in rescue operations.

The expression numbers needed to treat/harm may be applied to various parameters in rescue operations. In the context of Norwegian avalanche rescue operations in the period of 1996 to 2017, the simple ratio of completed search operations (n = 610) to the number of real rescues involving avalanche victims (n = 250) may serve as an indicator of organizational overcommitment (ratio of 1:7). Mair et al[30] reported nonvictim involvement in 56% of 221 helicopter avalanche rescue missions in the province of Tyrol in Austria (ratio of 1:8), concluding that this "can be reduced by a restrictive dispatch policy after avalanche accidents without clear information about human involvement." Numbers needed to treat/harm measures could be introduced as lagging risk indicators in avalanche rescue.

Crewmembers recognized several trajectories toward overcommitment. The rescuer activity that leads up to the point of becoming a dangerous act is very likely within accepted practice in "the space of possibilities" with "degrees of freedom to be resolved according to subjective preferences."[24] Apparent overcommitment may be experienced as rational, controllable, low risk by the rescuer in action influenced by what Neil D. Weinstein termed *optimism bias*.[31] Along with the "affect heuristic," these psychological mechanisms may explain why crewmembers found it difficult to detect overcommitment in real time. Over time, the optimism bias may be self-reinforcing, causing a wrong impression of being invulnerable.[31] In a recent study of accidents in mountain sports, Vanpoulle et al[32] found that ski tourers ventured out in conditions identified to be hazardous and that they minimized, ignored, or banalized risk factors. This underestimation of obvious risk was attributed to human factors like risk normalization[33] and heuristic traps.[34] Previous reports from Norwegian avalanche incidents[35] showed similar phenomena in that rescuers regularly exposed themselves to the risk of naturally released avalanches during rescue operations. In those cases, large groups of rescuers responded to the same accident sites, perhaps also trapped by social facilitation.[34]

Several of the causal factors may interact and converge to produce overcommitment. Slovic[28] argued that "extraordinarily generous behavior toward identifiable victims, then, could simply result from the tendency to altruistic behavior to increase with the proportion of the reference group." Crewmembers explained the ease with which they might reject a mission when at the base. Closer to the accident site, with an identifiable patient, there is an increasing tendency to experience victim allegiance, tunnel vision, mission creeping, target fixation, and expectations and external pressure. Rescuers, unlike ski tourers, cannot easily choose another place or another time and will consequently be left on the horns of a dilemma.

Conclusion

Norwegian air ambulance personnel have offered their reflections on the concept of overcommitment in medical evacuation and rescue operations. The results show that professional rescuers recognize overcommitment in a variety of situations. The concept is broadened to include both regular, everyday actions and hazardous rescue attempts in extraordinary incidents. These multifaceted aspects are included in our suggested definition of overcommitment—"situations in which rescuers make themselves or others vulnerable by committing more than is feasible, desirable, expected, recommended, or compellingly necessary in the given scenario and thereby run the risk of personal injury or death."

Although always aiming at a perfect balance between patient and rescuer safety, HEMS crewmembers find that a number of personal, social, organizational, and situational factors distort equilibrium. Their comprehensions and assumptions can be linked to parallel explanations in cognitive and social psychology, such as heuristics, biases, group dynamics, and interpersonal relationships. Heuristics, biases, and various psychological mechanisms may be difficult to discover and neutralize in an ongoing rescue operation. On the other hand, the causal factors mentioned by HEMS personnel form recognizable constellations of factors leading to overcommitment. These constellations may offer useful starting points for systems-based counteracting measures, which easily could be included in the regular CRM training for HEMS personnel.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.amj.2019.05.008.

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Paper IV

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Original Research

Overcommitment: Management in Helicopter Emergency Medical Services in Norway

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A B S T R A C T

Objective: Overcommitment in demanding rescue situations may put both rescuers and patients in danger. This study aimed at identifying individual approaches and organizational strategies that counteract instances in which rescuers commit more than is feasible, desirable, expected, recommended, or compellingly necessary. How is overcommitment managed by professional frontline rescuers during hazardous medical evacuation and rescue situations?
Methods: In a qualitative, exploratory study, 9 focus group interviews were conducted with a total of 30 crewmembers from the Norwegian Helicopter Emergency Medical Service.
Results: In this second article in a series of 2 articles on overcommitment, 12 commitment-moderating factors are presented. Air ambulance personnel pointed at sociological, cognitive, and organizational elements that may influence their degree of commitment in challenging and hazardous rescue situations.
Conclusion: Air ambulance personnel describe a team-based approach to adjust their level of commitment in medical evacuation and rescue missions. They rely on known, however important, nontechnical skills and organizational measures to combat overcommitment in demanding rescue situations. Some of their approaches to safe performance should be adoptable by other rescue units and less experienced voluntary, not-for-profit, rescue organizations.

The willingness to engage deeply and with individually and professionally based motivation for carrying out a defined mission forms the basis for high-quality rescue performance. As a core driving force, the individual eager to commit to saving lives should not be suppressed. However, one should acknowledge that the eagerness to engage deeply in such activities, often under harsh environmental conditions demanding decisions under a high degree of uncertainty, is not free of risk to those involved. Overcommitment (ie, when rescuers make themselves vulnerable by committing more than is feasible, desirable, expected, recommended, or compellingly necessary) may put both the mission and the rescuers at risk. These actions are commonly judged as isolated impetuous acts but may as well result from complex interactions of *behavior-shaping mechanisms*.[1] Unsafe actions reflect a control problem,[2] not solely along the horizontal axis representing the frontline rescuers but also in the vertical interaction of complex and sociotechnical integrated project organizations[3] like the rescue services.[1] Overcommitment can also imply futile use of resources. Therefore, it could also be analyzed in an economic perspective. Available resources are in general scarce. Therefore, it can often be a sensible question if they can be used with more benefit for other purposes. This is outside the scope of this article. The safety control structure[1,2] of the Norwegian rescue service reflects its systematic organization, implying that the final decisions on joint and coordinated efforts are to remain with the incident commander (IC). The IC relies on feedback from cooperating units (the team) for him or her to maintain an updated risk image,[4] especially because designated ICs may arrive much later than the rescue units handling the operational tasks.[5] Another factor to observe is that according to Norwegian legislation every single unit and person taking part in a rescue mission is obliged to adhere to legal requirements in the acts and regulations relevant to his or her work (eg, the health personnel have

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to follow the standards laid down in the health legislation). Therefore, the authority and responsibility for the IC are not in general extended beyond the need of coordinating joint efforts from different specialized resources.

Eivind L. Rake and Ove Njå[5] found that ICs made few decisions and relied on "tacitly understood routines and procedures" executed by the first responding individual rescuers. Regarding safety assessments, this means that the ICs mainly agree to recommendations from frontline rescuers.

What, then, do highly experienced rescuers do to avoid overcommitment in situations dominated by uncertainty and life-threatening hazards? In this article, we present how overcommitment is identified and managed by the frequent first rescue responders in the Norwegian Helicopter Emergency Medical Service (HEMS).

Methodology and Research Design

In this qualitative study, we conducted focus group interviews to explore how HEMS personnel in the Norwegian Air Ambulance Service (NAAS) adjust their level of commitment in various demanding medical evacuation and rescue situations.

The principle aims of this part of prehospital emergency medicine are the following[6]:

1. Bring emergency medical equipment and specially qualified health care professionals quickly to seriously ill or injured patients.
2. Bring patients to an adequate level of treatment in the health service during ongoing monitoring and treatment, including providing emergency medical diagnostics.
3. Perform simple search and rescue operations.

The NAAS operates with 3-man crews: the pilot, medical doctor, and HEMS rescue paramedic. On-duty crewmembers stay on the base 24/7 for up to 1 week at a time. The composition of the crews varies over time, but crewmembers are employed at 1 specific air ambulance base. More detailed descriptions of the NAAS can be found in the studies by Zakariassen et al[7] and Lunde and Braut.[8]

The interviewees were selected by way of convenience sampling.[9] Although the bases were selected by location, crewmembers were selected by random. Following general information about the project via NAAS channels, crews were contacted before or in the beginning of their duty period. All crewmembers were informed that participation was voluntary, and no one refused to take part.

Malterud et al[10] present a model for the assessment of sample size in qualitative studies in which information power is given by certain items. In this exploratory study, reflecting the broad aim, we interviewed a sufficiently large number of participants to counteract a biased data collection. Air ambulance crews were chosen because of their unique experience from prehospital critical care, allowing a smaller number of cases. Characteristic phenomena of overcommitment were expected to reflect established safety theory, effectively reducing the need for a large sample. A cross-case strategy of analysis was a natural choice to "produce new knowledge and augment existing knowledge and experience."[11] Although cross-case analysis requires a larger sample, this may complicate the analysis.[10]

Material

In the end, 9 crews, altogether 30 crewmembers, were interviewed in the period from March 2017 until April 2018. The interviewees were 3 women and 27 men aged between 30 and 60 years, with a mean age of 45. The mean length of experience from this kind of service was 10 years.

These focus group interviews were tape recorded, transcribed, anonymized, and summarized in written reports. Linguistic pause fillers and formulaic language were omitted. Group interaction was not considered a major issue in this study because air ambulance crews are small and the crewmembers are well acquainted. All reports were sent to the interviewees for comments and validation, in line with Plummer-D'Amato's member checking,[12] to enhance credibility and trustworthiness. All reports were approved without corrective comments. All tape recordings were deleted immediately after transcription.

The first author moderated the interviews. He is a member of volunteer mountain rescue organizations and a police officer. In these positions, he frequently cooperates with air ambulance crews. The second author is a medical doctor and professor in risk management and societal safety.

The interviews followed a common structure, with an initial presentation of the background for the study followed by a clarification of specific concepts and practical considerations. The interview guide contained 5 main themes: 1) associations with the concept of overcommitment, 2) recognition and sharing of operational cues, 3) causal factors in overcommitment, 4) preventive factors in overcommitment, and 5) overcommitment and learning. We did not apply strict limitations to the topics and discussions that arose from introducing the main themes.

The interviews were exported to the software program QSR International NVIVO 11 (QSR International, Melbourne, Australia) to aid in the necessary steps of systematic text condensation.[13] Starting from the original 5 main themes of the interview guide, the first step of the analysis resulted in a set of broad categories. A further subdivision yielded a number of "meaning units"[13] (ie, key words that describe and conceptualize the main findings of the study).

A more detailed description of methodology is presented in the first article in this series titled "The Concept of Over-Commitment in Rescue Operations: Some Theoretical Aspects based upon Empirical Data."

Results

The interviews of air ambulance crews elicited 12 key words summarizing their reflections on what may prevent overcommitment in hazardous situations. In the following sections, the interviewees are referred to by an uppercase letter and a number (eg, A1).

Anticipation

HEMS crewmembers often pointed at factors that enhance their ability to anticipate danger. D2 suggested, "Training, experience and communication, which can in some way capture the dangers and that some start it (anticipation) by just expressing the problem before we arrive." H3 said, "And we are always talking about the mission on the way out, going through where we are going, flight operative and medical things." D1 offered the following example: "And if there's mountain farm, there's a zip line." Thinking ahead of their present position, either when treating a critically ill patient or in low-altitude flying, was strongly dependent on acquisition and interpretation of the available information.

Contingency Planning

Closely linked to anticipation is contingency planning. F3 stated, "Then, I think we are quite good at this; OK, time out, new plan." Initial callout information is often scarce, and this requires constant adjustment of mental models as new information is available. To this end, crewmembers continuously exchange views on how to meet the situation. E2 explained, "On our way out, we will always discuss; what can we expect?" and then "make a coarse plan and fine-tune it." Their contingency plans also involve other resources, both to ensure as short a response time as possible and to release some of the pressure put on them to reach the patient's position. G1 said, "Yes . . . yes . . ., I always have a plan C, then, which is . . . It may be an emergency procedure."

Communication

Most crews listed communication, in all phases of missions, as a key factor in adjusting their level of commitment. E2 states, "It's the communication in the crew, then everybody is likely to sit with the same situation awareness ..." Premission briefings, exchange of information with collaborating rescue units, and a constant verbalization of observations as they approached the accident site are crucial communication techniques to increase and equalize team situation awareness (G1). J3 pointed at "filters" to prevent overcommitment, of which the first one is to "take a brief time-out" to allow people to exchange views on the nature of the mission, specifically about the patient's condition (E2). The initial internal discussion contributes to determine the degree of urgency and inherent risks. "We can get into real trouble if we do not clarify to the team, what we are up against" (G3). C1 mentioned that some new HEMS rescue paramedics "want to respond to everything" and explained humorously that he sometimes had to say "That will be without me." C2 explained, [This is] "how they facilitate (adjustment of commitment) if someone is very eager to go; it's through communication; by explaining and telling what you think, and then discuss."

Cue Recognition

"Personally, I dont̕ think I've become much better at thorough assessments and neat decision making, but I'm much better at capturing the signals around me ..." (G2). D2 explained that they pass various "layers," zooming in as they approach the accident site; first the map, then topography, terrain, high mountains, camping sites, and houses. "You know, always, as long as there's a road, there's often either wires next to it, or is it house, then it needs electricity." Cue recognition, communication, "gut feeling," and a low threshold for commenting on dangers and failures were often mentioned in the same breath, obviously linked to risk awareness. C1 illustrated this by saying, "You've been here before ... that is, now you are here ... It nearly went wrong here 5 years ago ... " The following conversation between crewmembers C1 and C2 clarify how they see "stomach feeling" with relation to experience: "What you say now is that you have a stomach feeling." "Yes, or experience, then." "And the stomach feeling comes from experience. Many talks about stomach feeling, but you cannot rely on your stomach feeling before you have experience."

Equipment and Sensors

Obviously, air ambulance personnel commit themselves to flying in less than ideal conditions, often over long distances, across climate zones and varying weather systems. In darkness and changing visibility, equipment like night vision goggles and a network of Web cameras increase their effective line of sight, thus reducing the need to "make a try." Crewmember E2 considered specialized equipment as a "a pretty obvious risk barrier." As C1 put it, "You should not go that far - you must cancel before you get there, because then it's often too late." C2 commented, "... earlier, when flying in darkness, they didnt̕ know what kind of weather they would meet, but now, we actually see the weather (by NVG)."

Experience

Crewmembers found that both task-specific and volume-based experience allowed crewmembers to choose more optimal solutions. "Because you do actually have the ability, because you are so well prepared with training and experience that; No, we will not do this." A2 reflected on his own decision making, "I was not so good, the first months, to assess the circumstances of what we did, then ..." D1 concluded convincingly, "We will never have 2 rookies in the cockpit ... That's in any case a requirement that we have." A1 remarked, "One thing we try to be a little conscious of is that we have a slightly different level of experience." They used affirmative questions as a common strategy to balance inequalities in the crew. E3 found experience "absolutely necessary" because "sometimes when it's difficult, you're in the borderland where it's the experience that decides." C1 thought that "It may have something to do with how we think, how we work together. We have been on many missions and we are maybe a little ahead."

Risk and Vulnerability Awareness

Crewmembers find that risk and vulnerability awareness can have a restraining effect on commitment. G2 stressed the importance of attention, saying "It's important to focus on what you are actually doing, rather than what you are going to do." In line with this, D2 reasoned about overcommitment and their perception of risk, "I think it's how you are as a person and how you're trained and how you interact with the rest of the crew, how you understand the danger, and that you describe that danger as real as possible. He continued, "To talk about a hazard, a concrete problem, is much better than just speculating about a possible future problem."

With reference to many sad accidents and their own experience with close calls, realizing one's own vulnerability was a game changer. G4 said, "The last accident made me realize that there is a certain risk involved, even if accidents are seldom." G2 referred to a specific mission, "No, we were, in a way, very much reminded of our vulnerability. We finished trying things ..." From feeling invincible and on top of all situations, feeling vulnerable leads them to a more defensive approach.

Quality and Flow of Information

Crewmembers pointed at acquisition and processing of information in the early stages of rescue operations as important factors affecting their level of commitment. J2 stated, "It's about gathering as much information as possible, from callout till you meet the patient, to be able to make as good an assessment as possible." A3 underlined that the dispatchers at the Emergency Medical Coordination Centre (EMCC) "get in a lot of information that makes them perceive the patient as really bad" and when they arrive " the world is completely different." Aiming at short response times, the crews seldom stall their flight for more information. As D2 put it, also demonstrating the dilemmas facing the first responders, "Firstly, if we are going to spend fifteen, twenty minutes before we go, there's no point in going at all - because then the patient is dead. We must have systems that make us go straight into the helicopter and save people." Especially in short-approach operations, the crew will not have time to adjust to the current situation, forcing them into premature and sometimes unprepared action.

Training and Preparedness

H3 found their position in the Norwegian rescue service as quite unique "because we spend our entire time at work just to be ready for action, go on missions and train ..." J1 stated that "... they have many training missions, where they go through all the points listed in the SOP, type of mission, potential hazards, route, fuel, status of aircraft and crew, weather ..." Unlike other responding units, from the ambulance or the police, they have no trainees or aspirants. This puts them in a "buffering" position, making them aware of how a certain level of knowledge and training influences their decision making in demanding situations. C2 stated, "In terms of overcommitment in the rescue service, I think it relates to knowledge. You want some doctors to assist the most critical patients, and similarly, you want some pilots to be flying when conditions are marginal." In line with this, F2 said, "I certainly believe that our (training) makes us more robust, because we have a similar mind-set, how we want this to work ..." Important parts of this training are crew resource management (CRM)[14] and the type of cross-training that results from assisting each other during missions. Indirectly, the dispatcher's level and type of training will affect the rescuers' degree of commitment. As C2 pointed out, "When people call the police for help, they do not get the same questions about the condition of the patient as if they call the EMCC."

Standard Procedures

Crewmembers experienced that standardization of training and procedures served as a mediator of commitment. F1 felt relieved by flight regulations, "If we fly to (a town) on a cerebral hemorrhage or respond to an avalanche accident in the mountains somewhere, we still fly through the same square tunnel . . . And then I can sit here, not having to take that decision about flying or not . . . to that baby. It's already taken for me." On the ground, the limits of safe practice are still subject to professional judgment, although checklists and procedures support standardized solutions. "They have checklists for avalanche rescue missions, so that they can go through them without getting all stressed up—it helps enormously" (J1). E2 referred to "a bottom line" of competence for all HEMS crewmembers represented by "The National Standard for HEMS Rescue Paramedics in the Air Ambulance Service."[15] H3 pointed out that they have "thousands of constellations of different crews in a year, as employees change bases and shifts," but this does not affect their general way of working "since everyone is in the same school."

Teamwork Behavior

Collegiality and rapport were frequently mentioned as essential factors for a sound decision environment. A3 commented that "it is about trusting each other's professional knowledge and it is part of their strength to be in a group with completely different skills." G1 said the following about detecting danger signs and communicating it: "What's good is that we live together and have dinner together, all week. That's the number 1, I think. We know each other." H2 found that "It's something about having this as our everyday experience which might be an advantage. We are used to sitting in a debriefing situation, we are relatively familiar with each other. Knowing each other makes it easier. Knowing each other's professions."

They also have a culture for expressing their own assessments and concerns, regardless of age and experience. C2 commented that "You need someone to ask all the critical questions," to "ignite the fuse," to make colleagues aware of dangerous situations. J4 said, "We have this culture; if anyone objects . . . if anyone is not happy, then we easily take a time-out." F3 said, "What is very important is the concept that all voices have equal value," referring to young volunteer rescuers who may find it difficult to speak up, even if they are rightly scared. F3 stated, "That`s a fine principle here; even though I don`t know much about flying, I actually have the right to ask questions and to be listened to . . ." A pilot commented, "Either we turn back, or I can try to explain what's my plan, so you can feel safer."

D1 explained that "we take the time we need to do it safely, and that permeates a lot of what we are doing; we dont̀ have to prove that we will get down there, no matter what." Crewmembers experienced that their safety culture had changed over time, "possibly, and especially after the accidents we've experienced." C2 underlined the importance of the team, "When we started working, we said there were two things guiding our work; it was the momentum theory and the chaos theory. No matter how much chaos surrounding us, we would have to stick together—find the right patient, do the right things—and leave."

Discussion

The nontechnical strategies used by HEMS personnel to stay safe in a complex rescue environment link in to known theoretical elements from high-reliability organizing,[16,17] collective mindfulness,[18] naturalistic decision making,[19,20] resilience,[21] CRM,[14] and teamwork behavior.[22] Listening to the crews leaves an impression that CRM is institutionalized, and uncertainty coping skills are operationalized (Table 1).

The multiprofessional composition of the HEMS crews added to their general experience from a variety of relevant sports and leisure-time activities creates a diversity that enables them to capture and understand more of the danger signals from their surroundings. "High Reliability Organizations (HROs) cultivate requisite variety and assume that it takes a complex system to sense a complex environment."[18] HEMS crews have learned through experience and CRM training that a constant and collective awareness of even the slightest sign of abnormality or danger will help them to avoid overcommitment and failure. As formulated by a HEMS rescue paramedic, "it is important to focus on what you are actually doing, rather than what you are going to do . . ." Mindfulness allows them to observe, recognize, react, and adapt to changes and variations in the rescue environment,[21] thus avoiding and curbing surprises and "unforeseen events" in a resilient manner. Recalling that the HEMS crewmembers constantly aim at balancing patient safety[23] and rescuer safety in all conditions and situations, a personal commitment is needed to build an "organizational culture of reliability."[16] Laws and regulations may have an indirect effect on the framework of rescue performance. HEMS crewmembers maintain that their final decisions to act safely are mainly based on knowledge- and skill-based competencies,[22] attitudes, experience, and teamwork behavior of rescuers (Fig. 1). This is much in congruence with the findings of Neal et al[24] that knowledge and motivation are "important determinants of safety behaviors." A major challenge, then, is that both

Table 1
Operational Uncertainty Management

Alarm	Seek information about *patient situation* and *rescue situation* (R) (2), use *equipment*/remote sensors/Web cameras (R) (2), ask affirmative questions (1), "red teaming" (1), active *communication*, «Huddle up» (R) (1), temporary *triage*, Is the mission possible?, *anticipate* situations and hazards (A) (3), call out back-up resources (F) (3).
En route	Connect with coordinators and other rescue units, *anticipate* situations (A) (3), discuss possible scenarios (A) (3), *communicate*, constant verbalization of observations (R) (2) (3), use remote sensors (R) (2), *contingency planning* (A) (3), *cue recognition* (2), ask affirmative questions (1), "red teaming" (1), report unease (1) (3), closed-loop *communication, share high-quality information* (R) (3), Say No (F). *Triage*, Possible to complete the mission?.
Arrival	Reconnaissance landing sites/hazard sites (F) (2), use established landing sites (F) (2), connect with rescuers on the ground (R) (2) (4), *contingency planning* (A) (3), *cue recognition* (2), request observation of obstructions (R) (F), *share high-quality information* (R), constant verbalization of observations (R) (2) (3), report unease (1) (3), ask affirmative questions (1), "red teaming" (1), Say No (F), Triage.
Response	*Cue awareness* (2), Connect with rescue specialists (R) (2) (3) (4). Report unease (1) (3). Say No (F). *Triage*, "red teaming" (1), apply *standard procedures* (F), constant verbalization of observations (R) (2) (3), stay/play/load and go (3).

Suggested activities to increase reliability, reduce and handle uncertainty, and prevent overcommitment in the various phases of ongoing medical evacuation and rescue missions. Words in italics are summarizing key words derived from the statements of helicopter emergency medical services crewmembers. Capital letters in parentheses indicate tactics of coping with uncertainty based on the R.A.W.F.S. heuristic.[a] Numbers in parentheses indicate elements of mindfulness.[b]

[a]R: Reduction, A: Assumption-based reasoning, W: Weighing pros and cons, F: Forestalling, and S: Suppression.

[b]1: Reluctance to simplify interpretations, 2: Sensitivity to operations, 3: Commitment to resilience, and 4: Deference to expertise.

Figure 1. HEMS crewmember decision fundamentals. Factors identified by Norwegian HEMS crewmembers to prevent overcommitment reflected from the formalistic statutory obligation to act.[25]

tactical and strategic managers have to make decisions based on information from first responders who are novices or nonexperts. This lack of predictability regarding the quality of observations and information from the accident site affect the risk and necessity assessments that are made by the approaching rescuers and, subsequently, the choice of rescue response.

Naturally, divergence in professional background, experience, resources, and rescue focus is an integral part of organized rescue activity. This may reflect the observed differences in how uncertainty is perceived and handled by the air ambulance personnel and other rescue units.[8] Crewmembers observed different reactions to signals of danger in members from the various organizations depending on their level of training and expertise. When responding to natural hazard incidents, cues like avalanche activity, wind direction, temperature changes, type of precipitation, and snow cover characteristics mean different things to different people. Over time, even danger signs may be perceived as normal, "weak, mixed signals that soon become treated mindlessly. . ."[18] as does the way we react to them. Only in hindsight is the pattern recognizable as a path to tragedy. This inherent variety of the rescue service may contribute to increased signal detection and failure-seeking behavior,[18] thus constituting a "conceptual slack"[26] that aids in self-evaluation and correction of performance. Of course, differing organizational cultures may also influence the common safety climate in an ongoing rescue operation,[24] causing a conflict about risk assessments and safety behavior.[27]

The CRM training encourages crewmembers to constantly verbalize "real-time observations and assessments of observations based on relevant cues in the clinical situation,"[28] so-called "online commentaries." Simultaneously, cross-training (ie, their knowledge of each other's professional duties) creates redundancy and mutual trust. It enables them to monitor the assessments and decisions of their colleagues, encouraging their colleagues to speak up if anything seems unreasonable.[22,29] Both anticipation and contingency planning are based on the crewmembers' mental models of the current situation. By verbalizing their thoughts on possible scenarios, they invite their colleagues to object and present alternatives, so-called "red teaming."[30] This will contribute to equalize their situational awareness. As interviewee C2 explained, "It's important that one of the crewmembers is the grumpy one and asks critical questions. If we all are very positive, we'll end up in situations where we shouldn't be . . ." This is of great importance in rescue situations in which success is strongly dependent on the effort of single crewmembers. The assumption is that objections to the chosen course of action may counteract suppression of uncertainty in critical decision making.

The HEMS crews' perception of the "3-crew concept" appears to be central to their general performance and also to the prevention of overcommitment. They rely on teamworking to keep them safe. Flin et al[22] explained teamwork skills as "behavioral interactions and attitudes that team members must develop before they can function effectively as a team." The reflections made by crewmembers indicate that the same "big 5" elements[31] making teams work effectively also make them work safely. The interviewees accentuated the value of active and trustful communication in their approach to avoid accidents. In line with the concept of resilience engineering,[21] safety is considered an integral part of HEMS operations.

We see that mindful organizing may prevent some acts of overcommitment (eg, those described as organizational overcommitment, low-risk–high-frequency overcommitment, and rule bending). Some situations will still be dominated by uncertainty in the last and decisive moments. Indecision is paid by the patient's chance of survival. There is no more available information, and a rescue effort is immediately required to save a life. When rescuers ignore this remaining uncertainty and make decisions based on their "stomach feelings" or just take a chance, they suppress uncertainty.[32] These are the moments that create heroes or fools. In such high-risk situations, postponing or stalling a rescue effort should always be an acceptable decision[33] based on the cautionary principle.[34] This is also the recommended approach in the Norwegian rescue services.[35] Forestalling, scenario and contingency planning, anticipation, assumption-based reasoning, and reconnaissance before landing/entering a hazard zone are all examples of cautious and mindful behavior.

Nontechnical skills or CRM is not a regular part of the training for nonflying rescue personnel in Norway, so conscious and focused teamwork behavior cannot be expected between rescue units. Based on the findings in this study, one may recommend specific interorganizational training based on "communication strategies within the relevant activity type that trigger actions that are relevant to safe practices."[28] Kruke and Olsen[36] suggest a foundation for reliability-seeking networks built on elements of high-reliability organizing and collective mindfulness. Although not all HRO characteristics occur simultaneously,[37] organized rescue operations display important HRO elements, which is in support of considering the Norwegian rescue service as a reliability-seeking network. Aiming at reducing the prevalence of overcommitment in rescue operations, future training of rescuers could benefit from a stronger focus on nontechnical skills.

Conclusion

HEMS personnel describe a team-based approach to adjust their level of commitment in medical evacuation and rescue missions. Their organizational structure, on-base duty time, CRM training, and frequent debriefing of missions enhance trustful and direct online team talk.[28] They recommend active communication and "red teaming" to increase individual and team awareness of both likely and unlikely accident scenarios, thus avoiding dangerous actions in dangerous conditions. In demanding missions, they rely on a combination of nontechnical skills, standard operational procedures, and organizational measures to identify and avoid harm's way. The most important measure to counteract overcommitment in the Norwegian rescue service may be an increased focus on interorganizational CRM-like training. This might create a safety climate that makes the complex and multifaceted rescue organization act like a team. Challenges will remain regarding the start-up phase of rescue operations in which highly motivated and less trained rescuers are tempted to engage in hasty and impetuous action. Managerial levels need to guide and support autonomous rescue units through the elements of operational uncertainty management to ensure that they stop in time.

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Paper V

1 A systems thinking approach to safety in Norwegian avalanche rescue operations

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Abstract

Snow avalanches crossing roads constitute a major safety challenge, to both road users and avalanche rescuers in Norway. In this paper, we reassess the current emergency response situation, by using systems safety theory. In two seminars, experts derived goals, hazards, requirements, constraints, a safety control structure and unsafe control actions from a systemic safety analysis of three avalanche rescue operations. The analysis was based on *the "Systems-Theoretic Accident Model and Processes"* (STAMP) approach and the *"Systems-Theoretic Process Analysis"* (STPA) technique. The gap analysis revealed that both dispatchers and emergency personnel lack the recommended training. First responders from the ordinary emergency services also lack basic avalanche safety equipment. This points at assumptions that are failing, as regards compliance with safety requirements, the operationalization of the safety control structure and what is common avalanche rescue practice in Norway. Common explanations of recurrent unsafe control actions were identified. Contrary to critics, the STAMP/STPA systemic safety analysis proved manageable and productive, as it unceasingly directed the analyst's attention towards organizational challenges at the blunt end.

Keywords: Avalanche rescue, rescuer safety, systems theory, STAMP, STPA, safety control structure, unsafe control actions.

1 Introduction

The Norwegian Public Roads Administration (NPRA) experiences approx. 220 snow avalanches hitting public roads each year (Busterud, 2016), occasionally leading to situations requiring assistance from the rescue services. In many of these situations, it is uncertain whether victims are involved in the avalanche or not, and high-risk search operations may be initiated without clear indications of a critical situation (Lunde & Njå, 2019). In a recent survey, we found that fifty percent of all recorded Norwegian avalanche rescue operations in the period 1996-2017 involved no victims (Lunde & Tellefsen, 2019). This high number of rescue operations with no human victims puts an extra burden on the rescue services and their representatives, and it may present a risk to the rescuers` own lives, which should be carefully considered.

Also, in situations involving avalanche victims, rescuers sustain high mission risk (Lunde & Kristensen, 2013; Mair et al., 2013), as a number of operations take place in challenging and complex avalanche terrain (Statham et al., 2006) during high avalanche danger (EAWS, 2016). A tragic example is the Drümännler accident in Switzerland in 2010 (Etter, 2010), where seven people died, including a doctor from the Helicopter Emergency Medical Service.

Incidents where rescuers spend time in avalanche runout zones in periods of considerable avalanche danger are undesirable but often underestimated. The recurrent nature of these incidents indicates that the normal practice in the Norwegian avalanche rescue system is somehow flawed. We raise the question of whether it is the organization of the rescue service and the routine interaction between managerial levels and rescue units that lead the frontline rescuers into hazardous situations. Is this a weakness of the rescue system in Norway, or could these incidents be tracked to contextual variabilities in the avalanche events and arbitrary mishaps during the response phases? We wanted to challenge the system approach to Norwegian avalanche rescue operations, based on manuals, procedures and through the experience of experts involved in the services.

In her approach to safety engineering, Nancy Leveson (2011) departs from traditional risk assessments and component failure thinking as a basis for safe operations. The ideas of foundational systems theory contain emergence, hierarchy, communication and control as prominent features. Leveson recommends that organizations establish objectives, requirements and constraints, to avoid increased risk levels. Safety is a control problem. The System-Theoretic Accident Model

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and Processes (STAMP) approach requires a hierarchical organization, in which feedback loops enable a higher level (the controller) to initiate proper (re-)actions, to maintain the system in a state of equilibrium and within safety limits. The accompanying System-Theoretic Process Analysis (STPA) is a technique developed to reveal why the identified hazards cause lack of control in complex organizations (2011, p. 211). We adopted these approaches to the Norwegian snow avalanche rescue system, in order to investigate their ability to reveal weaknesses in and between services involved in the missions. We also wanted to challenge Underwood et al.'s (2012) criticism that systemic accident analysis (SAA) is mainly used by researchers and that it has little resonance amongst practitioners in industry. Amongst the reasons for not applying SAA are the comprehensive training requirements. Their view on training requirements was a trigger for our project, because we were not intimidated by Leveson's approach, which we rather found to be how the rescue services inherently comprehend the system, albeit not analysing it as such. Against this background, we sought an approach in which we could involve practitioners and experts in a holistic analysis of the avalanche rescue service, without spending their time on SAA-specific training.

In a system-theoretic approach, it is assumed that the system is presented and forms the basis for the further analysis. The Norwegian avalanche rescue service is a complex system that we briefly introduce below. The system is modelled from procedures and guidelines, as well as expert opinions obtained through the STPA seminars.

Figure 1 represents the experts' understanding of the structure and command system of the Norwegian avalanche rescue service, and which controllers and actuators are involved in avalanche rescue operations. The structure defines the boundaries of the system and, thus, encompasses the system hazards addressed in this study. It is a system of systems (Maier, 1998), involving a minimum of three public agencies, military helicopters and several voluntary rescue organizations.

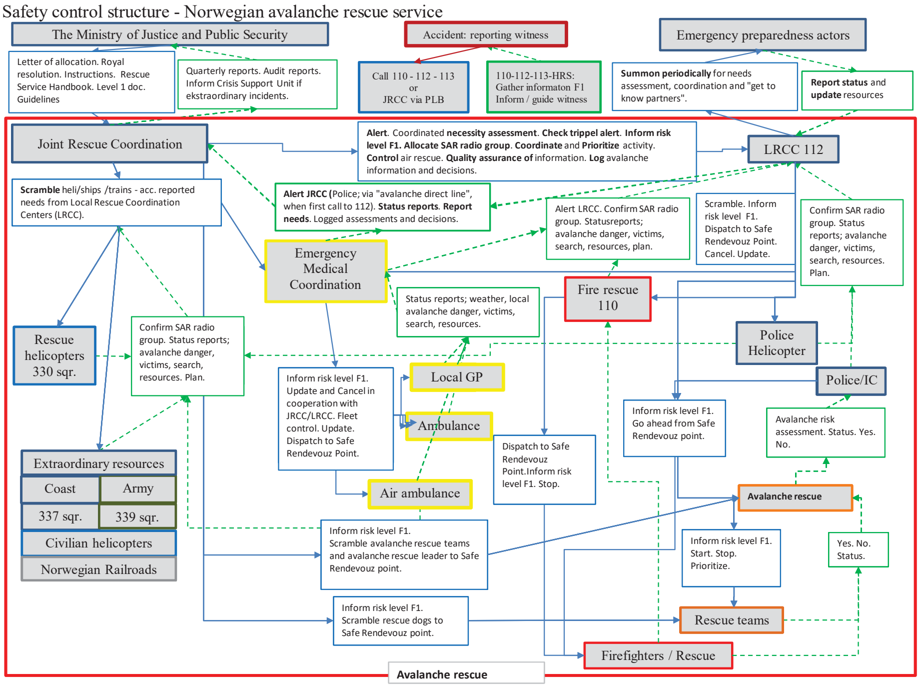

Figure 1. Safety control structure of the Norwegian avalanche rescue system. Grey boxes: Controllers. Blue continuous arrows: Control activities. Green dotted arrows: Feedback. The surrounding red rectangle indicates which controllers and activities are involved in avalanche rescue operations.

The Norwegian Rescue Service is based on the collective efforts of professional, volunteer and private institutions and organizations, in which the two Joint Rescue Coordination Centres (JRCC) North- and South and the Local Rescue Coordination Centres (LRCC, situated at the regional police headquarters) are responsible for the initiation of rescue operations and the subsequent deployment of rescuers to the accident site. The Ministry of Justice and Public Security is the superior administrative office responsible for emergency preparedness and crisis management. The JRCCs are responsible for the overall management of rescue operations and the supervision of the LRCCs. The police are responsible for the initiation and management of rescue operations in their respective geographical areas, whereas all participating organizations are responsible for their own emergency preparedness and safety management. By design, it is a top-down system, with an exponential increase in separate control loops as one gets closer to the accident site.

Distress calls are received by the JRCC, the police / LRCC, the health service Emergency Medical Coordination Centres (EMCC) or the Fire and Rescue Coordination Centres (FRCC), with the subsequent activation of the respective rescue resources. Other rescue organizations are called out to emergencies that cannot be handled solely by the dedicated emergency services. In the case of road-related avalanche incidents, volunteer rescuers possess the manpower and technical rescue expertise. These resources are called out to assist in rescue management, avalanche risk assessment, searching of the avalanche debris, excavation, first aid treatment and evacuation of victims. In all phases, although independent as organizations, they face interdependencies in their actions to carry out lifesaving rescue activities.

The safety analysis presented in this article contains document analysis of governing documents and literature framing the avalanche rescue service, and two distinct seminars with national experts on operative rescue missions. The aims of the safety analysis were to:

1: Identify goals, hazards, requirements and constraints.

2: Derive the safety control structure of the Norwegian avalanche rescue service (Fig. 1).

3: Identify recurrent unsafe control actions in the Norwegian avalanche rescue system.

4: Evaluate STAMP and STPA as methods for analysing risk and safety in the Norwegian avalanche rescue service.

2 Methodology

2.1 Study design

We invited six Norwegian experts to analyse safety for rescuers in avalanche rescue operations. In two seminars at the Centre for Societal Safety in Rogaland, Norway, in-depth discussions were based on three historic Norwegian avalanche rescue operations in a cross-case strategy of analysis (Khan & VanWynsberghe, 2008). These operations were:

- Avalanche hitting a road in Gyadalen, Rogaland, 2011. A snowplough truck was avalanched into a lake in a high avalanche risk area, and rescue units were deployed during the night, in darkness and adverse weather conditions.
- Avalanche hitting a road at Kattfjordeidet, Troms, 2013. Parked cars were hit by avalanches in a popular backcountry skiing area, and several neighbouring avalanches descended during the search and rescue operation.
- Avalanche accident in Aurland, Sogn og Fjordane, 2016. A backcountry skier was fatally injured when avalanched down a steep gully, and multiple helicopters and other rescue resources were deployed in the area.

These operations demonstrated specific challenges related to both rescuer and patient safety. The assumption was that undesirable incidents could be linked to a lack of control of activities at various levels in the rescue management hierarchy.

The seminars were structured to comply with the STAMP approach (Leveson, 2011, p. 233) using the STPA technique. The experts had no prior training in STAMP-based safety analysis. The first seminar focused on a preliminary hazard analysis and the safety control structure. The moderator (the first author) started by introducing the group to the STAMP methodology and the three cases. The second seminar was a stepwise and detailed hazard analysis, based on the STPA accident analysis technique.

2.2 Selection and data collection

During the safety analyses, all levels of the avalanche rescue system were represented, apart from the LRCC.

An incident commander (IC) from the police answered for this controller. The group varied between the two seminars: the IC level was absent at the first and the JRCC level was absent at the second seminar.

The seminars took place in November 2017 and February 2018. Each seminar lasted 6 -7 hours. The data collection resembled focus group interviews, *"to explore specific topics, and individuals` views and experiences, through group interaction"* (Litosseliti, 2003, p. 1). In both seminars, the moderator guided the discussion to cover the necessary steps included in the STAMP approach. Prior to the seminars, the participants were supplied with background information and tools pertaining to the STAMP approach, including a preliminary safety control structure of the avalanche rescue service. The level of detail of analysis corresponded to what could be identified at the normal hierarchical levels in the rescue service.

We tape recorded both seminars to support transcription and summary. The material was transcribed immediately after the interviews, and the electronic sound files were deleted. The written reports consisted of short summaries in combination with full transcriptions. Following write-up, the reports were sent to the individual interviewees for comments and validation, in line with Prudence Plummer-D'Amato´s member checking, to enhance credibility and trustworthiness (2008). Comments were imported in the final transcriptions. The reports formed the basis for further discussions and analyses.

2.3 Analysis

In the written report from the first seminar, all statements made by the seminar participants were categorized according to STAMP terminology, e.g. goals, hazards, loss events, requirements, constraints, controller, unsafe control action and scenarios. This was done by colour coding and rearrangement of the text to form clusters of similar STAMP statements. In this approach, all statements uttered during the discussions were used as a part of the analysis, irrespective of chronology or topic in question. The statements were then rephrased into hazards, system requirements, control actions, feedback and elements of the safety control structure.

In the second seminar, typical STAMP tables and figures were presented on screen to support the discussion and ensure a structured approach. As the analysis progressed, findings were added directly to the illustrations on screen and later included in the seminar reports. The interpretation and transfer of statements into the STPA analysis was done by the first author in a dialogue with the experts.

3 Results

The safety analysis provided specific goals, hazards, requirements and constraints, which can be made applicable to the Norwegian avalanche rescue service; we refer to Appendix A. In this section, we concentrate on the safety control structure of the avalanche rescue service and the control loops involved in the dispatch of rescue resources and the safeguarding of patient and rescuer safety. We considered two control activities to be critical to reaching the goal of safe and efficient rescue performance:

- ***JRCC/LRCC/EMCC/FRCC:*** Initial assessment of the victim`s situation and avalanche risk in the area, based on information from the reporting witness and additional investigations, and subsequent decision on rescue response; a situation-specific dispatch and prioritization of rescue resources.
- ***Rescue unit leaders:*** Initial assessment of rescue situation, based on information from dispatch centres and additional investigations, and subsequent decision on rescue response; mobilization of adequately trained and properly equipped rescuers.

The safety control structures related to the activities of the dispatch and prioritization of avalanche rescue resources are presented in Figure 2.

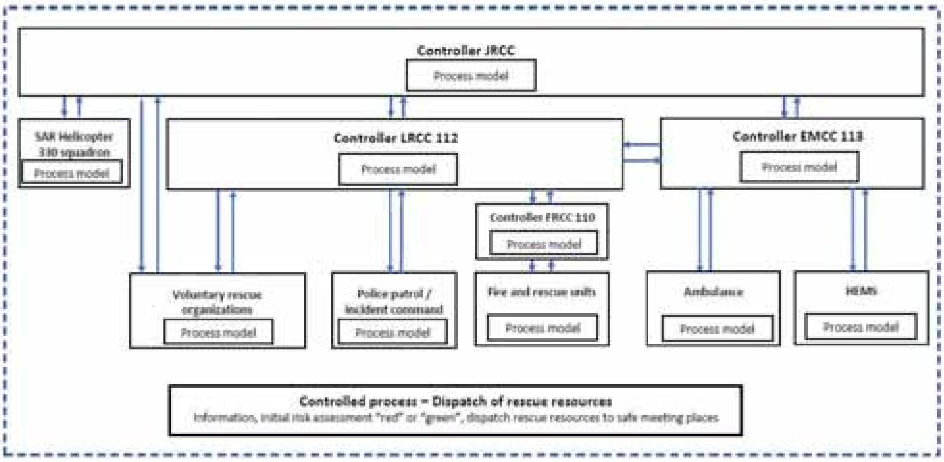

Figure 2. Controllers and control loops involved in dispatch of avalanche rescue resources. The arrows indicate control actions and feedback loops. The blue dotted line encloses the controllers and actuators involved in avalanche rescue operations. Initial risk assessment “red” or “green” in the bottom box refers to the conclusion and framing of the mission; “red” is considered a complex and risky mission, whereas “green” is considered a straightforward mission without noticeable risk to rescuers (Kristensen et al., 2007; Lunde & Kristensen, 2013). Abbreviations: JRCC: Joint Rescue Coordination Centre; LRCC: Local Rescue Coordination Centre; EMCC: Emergency Medical Coordination Centre; FRCC: Fire and Rescue Coordination Centre; HEMS: Helicopter Emergency Medical Service; SAR Helicopter: Airforce operated Search and Rescue helicopter.

We notice from Figure 2 that volunteer rescuers can be dispatched from at least two different controllers (JRCC and LRCC). Important first rescue responders like the air rescue helicopters and HEMS are dispatched from other controllers (JRCC or EMCC) than the LRCC. The LRCCs do control the police helicopter stationed in Oslo, but this resource is an infrequent responder in avalanche accidents and therefore left out of this figure. The JRCC has the final say on which helicopter resources are to be dispatched to the accident site. However, avalanche accidents are considered to be medical emergencies, which are handled by EMCCs on an independent basis. Fire and rescue units are dispatched from the FRCC, usually on request from the LRCC. The first call from victims or bystanders may go to either of the three emergency call centres (FRCC (110), LRCC (112), EMCC (113)) or directly to the JRCC. Standard procedures require immediate mutual exchange of information between the coordination centres.

3.1 Responsibility and gap analysis – findings

Following the identification of system requirements, the analysis group discussed whether any of the requirements are not put into action. Important points to consider were (Johnson, 2016; Leveson, 2011):

- Who is responsible for which system requirements, and are any requirements not being implemented, met or controlled?
- Is the safety control structure congruent with existing or new requirements?
- Do we observe uncertainties in cooperation and communication due to flawed coordination?
- Are there multiple controllers, controlling the same process?

3.1.1 Dispatchers and emergency personnel lack training and avalanche safety equipment

The main finding was that important controllers at the LRCC and the EMCC, and frequent first responders from the emergency services, are not provided with proper training and equipment for avalanche rescue.

3.1.2 Coordination risk

The JRCC, EMCC, LRCC and FRCC are all in a position to scramble and coordinate both air and/or some of the same terrestrial rescue resources. This could result in misunderstandings about control responsibilities, missing feedback and interruption of the control loop, or conflicting control actions. Inadequate coordination could result from delays in the mutual exchange of information, missing or late notifications between control centres about avalanche emergency calls, lack of information in the start-up phase and technical shortcomings in communication channels.

3.2 Unsafe control actions

The potential unsafe control actions (UCA) stem from the hazards and system requirements, and a selection is presented in Table 1. In this table, we linked the control actions to common "managerial control actions" (Helferich, 2013). The control actions are generalized to encompass several controllers. We did not allocate these hazards to specific events or scenarios.

Table 1. Select summary of STPA step 1, The Norwegian avalanche rescue service, based on the identified hazards. The table is based on Helferich (2013).

Classes of managerial control actions[1]	Control action	Unsafe control action: *A control action required for safety is not provided or is not followed*	Unsafe control action: *An unsafe control action is provided that leads to a risk*	Unsafe control action: *A potentially safe control action is provided too late, too early, or out of sequence*	Unsafe control action: *A safe control action is stopped too soon or applied too long*
Set goals and direction – for emergency preparedness planning	LRCC: Map and summon all emergency preparedness actors periodically.	LRCC: Does not map and summon relevant actors for coordination and "get-to-know-each other".	Rescue units allow untrained personnel to be on call to respond to avalanche accidents.	N/A	N/A
Establish work processes and standards – to ensure dispatch of the right rescue resource to the right place at the right time	All: Establish efficient and safe dispatch routines.	LRCC: Does not routinely dispatch snow safety specialists in infrastructure related avalanche rescue operations. LRCC: Does not routinely order rescuers to stop at predetermined safe meeting places in avalanche danger level 3-5 conditions.	All: Dispatch incompetent and unequipped personnel in infrastructure related avalanche rescue operations.	LRCC: Call out avalanche rescue leader / snow safety specialist after dispatch of rescuers.	LRCC: Call out of rescue resources is stopped before the situation is clarified.
Staff and train – personnel in all organizations to ensure efficient and safe rescue response	All: Provide all responding rescue personnel with avalanche rescue training.	All: Rescue organizations do not train and equip their personnel for avalanche rescue operations.	Police/IC: Police base their incident commanders in distant locations.	LRCC/EMCC: Allow untrained personnel to be on call for avalanche emergencies.	N/A
Manage facility and equipment – to ensure that all rescue organizations provide their region and their rescuers with relevant rescue equipment	All: Obtain and allocate relevant avalanche rescue and safety equipment to all rescue units and individual rescuers.	All: Rescue organizations do not supply their rescuers with tracking devices and avalanche safety equipment.	LRCC/EMCC dispatch police units and ambulances to the accident site without avalanche safety equipment.	N/A	N/A
Allocate resources – according to the situation at the accident site and avalanche risk level	LRCC/IC: Postpone / cancel rescue efforts. LRCC/EMCC / JRCC: Dispatch key personnel swiftly to the accident site.	IC does not postpone rescue efforts in uncertain and dangerous conditions. LRCC/EMCC/JRCC do not dispatch the closest and most competent medical resource directly to the accident site.	IC postpones rescue efforts in acceptable conditions. LRCC dispatches the IC from distant locations with long travel time.	IC stops rescue efforts too late in increasingly dangerous conditions. First responding HEMS / Air rescue personnel are detoured or kept waiting for other rescue personnel.	IC stops rescue efforts too early in manageable conditions. IC allows rescue efforts to continue in dangerous conditions.
Monitor, evaluate performance – to ensure safe operations and continuous improvement.	JRCC/LRCC/IC: Initiate formal evaluation of all avalanche rescue operations and report findings.	JRCC/LRCC/IC do not systematically debrief avalanche rescue operation.	N/A	N/A	N/A

3.3 Causal analysis – STPA step 2

The analysis disclosed that many unsafe control actions shared common causes, of which the most frequent was inadequate control algorithms. In Figure 2, we present the analysis of the UCA: *"Dispatch incompetent and unequipped personnel in infrastructure related avalanche rescue operations"*. This UCA frequently leads to situations where first responding rescue units from the ambulance service, the police and local fire and rescue departments are exposed to high avalanche danger on public roads. Figure 3 shows the controllers, control loops and possible control flaws involved in the dispatch of rescue resources.

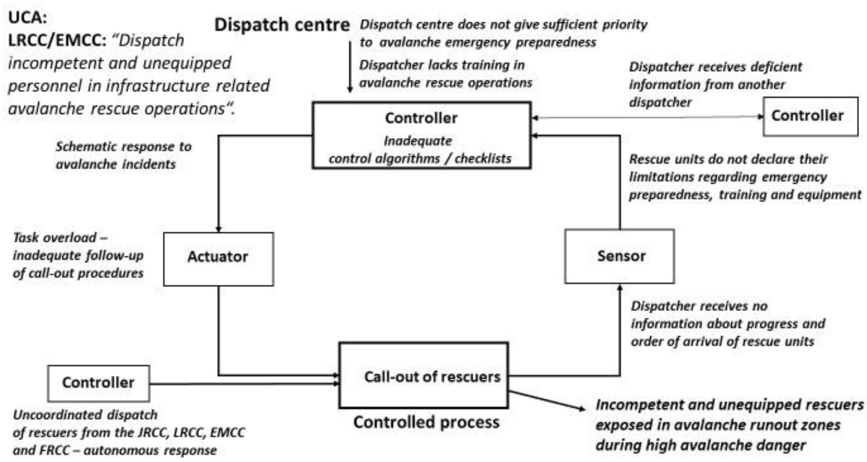

Figure 3. Control flaws related to the unsafe control actions (UCA): *"Dispatch incompetent and unequipped personnel in infrastructure related avalanche rescue operations"*. The figure is based on the control loop presented in (Leveson, 2013; Leveson & Thomas, 2018) and (Thomas, 2013). Abbreviations: JRCC: Joint Rescue Coordination Centre; LRCC: Local Rescue Coordination Centre; EMCC: Emergency Medical Coordination Centre; FRCC: Fire and Rescue Coordination Centre.

4 Discussion

4.1 Failing assumptions

When looking at the structure and hierarchy of the Norwegian avalanche rescue service, safety should emerge from normal operations, i.e. systematic, continuous and transparent avalanche risk assessment and management activities in all components of the rescue system (Leveson, 2011, p. 67). The experts in this study maintain that this quality requires specific training and competency at all levels. Systematic avalanche rescue training is not common in the ordinary terrestrial emergency services, and only seldom do they bring avalanche safety equipment. This finding points to a serious gap between the assumption, which is expressed by instructions (Regjeringen, 2013, 2018), guidelines (NRR, 2012), the identified safety requirements and the safety control structure, and what is common avalanche rescue practice in Norway. It also deviates from the regulations laid down in the Norwegian *"Working Environment Act"* Section 3-2, Special safety precautions (Fougner & Holo, 2006; Regjeringen, 2005), stating that employees are *"to receive the necessary training, practice and instruction"*; that supervisors (controllers) must have *"the necessary competence to ensure that the work is performed in a proper manner with regard to health and safety"*; the employer must ensure call out of *"expert assistance, when this is necessary"* and that *"satisfactory personal protective equipment is made available to the employees"*, and that *"the employees are trained in the use of such equipment and that the equipment is used"*. The assumption is that avalanche emergencies are handled by trained and fully equipped rescuers, from beginning to end. The reality is that the first and most critical phase of these rescue operations is often handled by untrained and unequipped personnel from the emergency services. In exceptional cases, local and individual initiatives have led to a higher degree of emergency preparedness.

The Norwegian *"National Guidelines for Avalanche Rescue Operations"* (NRR, 2012) contain recommendations regarding training, competency and safety procedures. A lack of compliance with the safety requirements demonstrates a lack of control, which in this case means that untrained rescuers frequently end up in avalanche runout zones, without safety equipment (undesirable incidents). Andrew Hopkins (2011, pp. 24-25) discusses the implementation of *"prescriptive technical rules"* and concludes, regarding the appropriateness of such rules, *"First, where industry good practice is agreed, it makes sense to formulate it as a clear rule so that laggards can be forced into line"*. The national guidelines for avalanche rescue describe international best practice and are, as such, prescriptive in their intentions. To regain control, i.e. to reduce undesirable incidents, all actors in the rescue service need to demonstrate compliance with laws, regulations and recommendations (system requirements and constraints) and consider them prescriptive rules. This is also the basis for the STAMP approach.

Another assumption is that the police, hierarchically, are meant to act as a continuous controller at multiple managerial levels in the rescue service. The results from this study indicate that they do not meet the expectations laid down in instructions (Regjeringen, 2013, 2018) and guidelines (NRR, 2012). This contributes to a deficient control of rescue operations in the critical first hour, and a suboptimal dispatch and prioritization of rescue resources could affect the survival chances of avalanche victims (Lunde & Tellefsen, 2019).

4.2 Coordination risk

The safety control structures in Figures 1 and 2 demonstrate the complexity of the required coordination in avalanche rescue operations. We see multiple controllers, overlapping and boundary areas of responsibility and complicated communication lines. Avalanche accidents require short response times (Brugger et al., 2001), so the dispatch of rescue resources is to be effectuated consecutively and in a prioritized order from the various dispatch centres. We see three challenges that may arise from a situation where multiple rescue resources are dispatched from multiple dispatchers: Firstly, the control algorithms may differ between dispatch centres with overlapping responsibilities, causing ambiguity and conflicting control actions (Leveson, 2015, p. 28). Secondly, some of the rescue units can be dispatched from several dispatch centres, giving rise to misunderstandings about the order and priority of rescue resources, and inadequate coordination through ambiguity about vertical coordination responsibility (Johnson, 2016, p. 74). Thirdly, it is the travel time that decides which rescue unit will be the first to arrive. It is a *"first come, first served"* situation, which is contradictory to the *"safety first"* (Blancher et al., 2018; Garrison, 2002; Regjeringen, 2018) attitude which is required in high avalanche risk situations. In effect, operational avalanche risk assessment is left to the individual rescue units, with only critical decisions to be formally approved by the incident commander and the rescue coordination centres. This is a system which places few constraints on the first responding, autonomous, and sometimes untrained, rescue units.

This coordination risk may be analysed further on the basis of factors like accountability, predictability and shared mental models (Okhuysen & Bechky, 2009). Both accountability and predictability arise from the hierarchical nature of the rescue service but could be improved by closer cooperation and sharing of knowledge between controllers from the different dispatch centres. The situation could also benefit from a sharper delineation of areas of responsibility.

Since the time of this study, the mutual notification between emergency call centres about search and rescue situations has been institutionalized by a specific *"SAR alert"* routine. This is to ensure information exchange, a swifter alert and dispatch of important rescue resources, and to improve coordination between emergency call centres in the initial stages of rescue operations.

4.3 Inter- and intra-controller variability

The analysis reveals that intra- and inter-controller variability gives unlimited combinations of controllers, actuators and contexts. In practical terms, a control action which is safe in one context can be unsafe in another (Thomas & Leveson, 2011), depending on the expertise of the given frontline rescuer. So, the management of avalanche risk is coincidental, not systematic. To avoid hazards that arise from the alignment of unsafe control actions and worst-case environmental conditions (Leveson, 2011, p. 184), safety constraints must be in place and known to all managerial levels. There is, therefore, a need to engage all actors in a common process of identifying basic goals, hazards and system requirements.

In this context, we face a recurring challenge linked to *"the collective understanding of what is dangerous, and how to contribute to reduce the hazards"* (Aven et al., 2004, p. 34). We see that the perceived obligation of professional emergency personnel to act (Clark, 2005; Myhrer, 2013) and a lack of formal avalanche rescue training may contribute to this challenge. One of the experts in this study commented that police officers must accept a certain risk level in their daily work, and that they perhaps also uphold this attitude in rescue operations: *"Yes, we see the risk involved, but we need to go in..."*. The rescuers` perceived obligation is probably stronger than the formal obligation laid upon them, since a prerequisite for the duty to act is training, safety equipment and a reasonable chance of succeeding in the rescue effort. Smith et al. (2019, p. 5) conclude that paramedics` decisions in high-risk situations will depend more on *"individual risk assessment, perception of risk, and their value systems"* than formal guidelines. In the context of avalanche rescue operations, this statement is in strong favour of providing all rescuers with the necessary training and tools for operational uncertainty management (Lunde & Braut, 2019) and avalanche risk assessment (Lied & Kristensen, 2003, p. 119; NRR, 2012). Also, the initial framing of the mission by the emergency call centres, e.g. by offering an initial assessment and conclusion about mission risk (Bründl & Etter, 2012; Kristensen et al., 2007; Lunde & Kristensen, 2013), in the right way and in the right order, will be likely to influence the rescuer's situation awareness and risk perception (Perrin et al., 2001; Sadler et al., 2007).

A question can be raised regarding the attainability of normative managerial constraints in a dynamic and constantly changing rescue environment, as operational risk requires a range of ad hoc adaptable approaches that may well fall outside prescriptions. In fact, general and well-documented injunctions may not make any real contribution to the safety of rescuers caught by conflicting interests but rather act as *"connivance by management"* (Ash & Smallman, 2008, p. 46). Facing such dilemmas, without pertinent and updated information on local avalanche risk, the rescuers may revert to the dangerous strategy of suppressing uncertainty to fulfil their task (Lipshitz et al., 2001). The role of system requirements will be to forestall these situations by ensuring that safety emerges as a property of the avalanche rescue system – the ordinary avalanche rescue activities on all hierarchical levels (Leveson, 2011, p. 64).

4.4 System-Theoretic Process Analysis of the Norwegian avalanche rescue service

The practical usage of the systemic accident analysis models is debated. Underwood et al.'s (2016) experience was that the STAMP analysis process was complicated and hard to understand. The selected approach to STPA in this study did not require the experts to have an in-depth knowledge of the analysis technique. It did, however, require active moderators to keep the discussions along the track of the STAMP-based process. The subsequent transcription and analysis of discussions, a process resembling focus group interviews, was laborious but offered the opportunity to include all parts of the discussions in the analysis.

The group of experts found the meetings inspiring, rewarding and useful. The major part of the participants´ time was spent discussing topics which were rooted in their experience and the three cases. As expressed by one of the experts: *"It would be more inhibitory to be too theoretical and methodical in the approach, versus doing it through a slightly more open perspective – as it is done here"*. The experts expressed concern about the level of detail needed to analyse all functions and organizations in the rescue service. It could also be difficult to know how to best contribute, if not totally oriented about which step in the STAMP process was being discussed. They also stressed the importance of involving technical staff (rescuers) in the discussions, to ensure a holistic analysis.

The STPA analysis process directed our focus towards the functions of the avalanche rescue system and pointed to important systemic causes to the identified hazards. It is, however, challenging to present the findings in a quick and coherent manner, since there may be several UCAs that are linked to the same undesirable scenarios. Blandine Antoine (2013) advocates the use of a *"Step 2 Tree"* to structure the findings of the causal analysis. This resembles a fault tree analysis, in which the sub-categories of scenarios follow a logical structure to describe how unsafe control actions are created. The sub-categories can be later be mapped into a control process loop, as shown in Figure 2 in this article.

Due to the level of detail, it may be rational to leave the analysis of individual control activities to the controllers at the corresponding levels in the safety control structure. This may also help to raise the awareness and commitment of those who are closest to the problem. Systems theory and Leveson's approach change the mindset for people involved in the avalanche rescue service, which is closely related to resilience. Continuously adapting to rescue situations and being aware of constraints are feasible for the personnel involved and, at the same time, will enhance ownership of the rescue safety management process.

5 Conclusion

A systemic accident analysis of the Norwegian avalanche rescue service revealed several hazards, requirements and constraints. Based on the safety control structure of the avalanche rescue service, a gap analysis identified failing assumptions regarding the preparedness of rescuers and the overall compliance with regulations and guidelines. These gaps could lead to undesirable incidents, in which untrained and unequipped rescuers end up in runout zones during high avalanche danger. Lack of compliance with recommended levels of training may also influence the dispatch and prioritization of rescue resources, affecting patient safety. Multiple controllers, overlapping areas of responsibility and complicated communication lines imply a risk for coordination flaws. The avalanche rescue system also shows great variability in competency and performance, which renders the management of avalanche risk coincidental, not systematic.

The STAMP/STPA approach to SAA proved to be an overall viable alternative, considering that the attention is unceasingly directed towards organizational challenges at the blunt end. The selected approach inspired by focus group interviews left the participants with ample time for discussions and little time needed for SAA training. A systems theory focus which permeates all managerial levels could also function as a mind changer for rescuers in operative situations, increasing the awareness of how individual actions affect the overall avalanche rescue performance.

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Appendix A

Interview guide to focus group interviews

Over-engasjement
Fokusgruppeintervjuer

Intervjuguide

Innledning:
"I forbindelse med en undersøkelse om norske skred-over-veg-aksjoner, fant jeg ut at mange, ganske omfattende, søk-og redningsaksjoner ble gjennomført under potensielt farlige forhold. Farlige forhold i denne sammenheng var kombinasjonen av terreng, snø og vær som tilsa at naturlig utløste skred kunne forventes å ramme innrykningsveger eller skadested i innsatsperioden. I en del av disse aksjonene var det registrert og loggført ulike tegn på fare, f.eks ny skredaktivitet i nærliggende områder eller svært ugunstige værforhold, uten at det tilsynelatende fikk noen direkte innvirkning på mannskapenes gjennomføring av oppdraget. I tillegg viste det seg at de fleste skred var tomme, altså var det ingen å lete etter. Jeg tolket dette som en form for "over-engasjement", som jeg definerer som et engasjement som fører til at en strekker seg så langt at det går på bekostning av hensynet til egen sikkerhet – og kan føre til ulykker som rammer redningsmannskaper.

I denne undersøkelsen vil jeg prøve å finne ut mer om over-engasjement ved å spørre faggrupper som har mengdetrening med operasjonell risiko og risikostyring. Selv om min undersøkelse gjelder risikostyring ved snøskredaksjoner, så vil all erfaring med over-engasjement være relevant for undersøkelsen. Jeg er derfor takknemlig for alle innspill og erfaringer som kan bidra til å belyse denne problemstillingen".

Populasjonen (kun for bruk som aggregerte data og felles beskrivelse av populasjonen):
1. Alder og kjønn.
2. Fagbakgrunn (lege, redningsmann, pilot, frivillig i redningstjenesten)?
3. Antall års erfaring i denne tjenesten?

Intervju – tema og spørsmål
Kort innledning om fokusgruppeintervju som metode; vekt på åpne spørsmål, få fram den enkeltes erfaring, betydningen av å lytte, vise til eksempler og diskutere. Informasjon om behandling av datamaterialet; om lydopptak og rutiner for sletting, om resymé og gjennomlesning, om anonymisering.

1. **Hva assosierer dere med over-engasjement?**
    a. Kjenner dere igjen fenomenet som jeg har beskrevet som over-engasjement?
    b. Har dere andre begreper som beskriver samme fenomen?
    c. Er over-engasjement et tema i.f.m. oppdrag?
    d. Har dere opplevd over-engasjement i tjenesten?
        i. Hvordan artet det seg?
    e. Er over-engasjement nødvendig og nyttig?
        i. Et nødvendig offer for å hjelpe?
    f. Hva med det motsatte – under-engasjement?

2. **Gjenkjennelse av faretegn ("Cue-recognition"):**
    a. Hva er typiske faretegn i deres virksomhet?
        i. Hvordan har dere identifisert disse faretegnene?
    b. Hvordan omtales og håndteres faretegn i deres virksomhet?
    c. Er faretegn noe som en oppdager mens aksjonen pågår, eller ved senere refleksjon?
    d. Oppfattes faretegn likt innad i mannskapet, uavhengig av fagbakgrunn og erfaring?

3. **Om årsaker til over-engasjement?**
    a. Hva mener dere er årsaken til over-engasjement?
        i. Hva eller hvem bidrar til over-engasjement?
        ii. Spesielle pasienter/ulykkesofre som utløser over-engasjement?
    b. Er det noen spesielle situasjoner som kan utløse over-engasjement?
        i. Har dere identifisert slike situasjoner på forhånd?
        ii. Er mulighet for over-engasjement et tema undervegs til et skadested?
    c. Hva med over-engasjement og "konkurranse" mellom redningsenheter?
    d. Har utstyr, tilgjengelighet og kapasitet, betydning for engasjementet?
    e. Hva med skadestedets tilgjengelighet?
    f. Er evaluering, gransking og eventuelle klager noe dere tenker på ved beslutninger om å fortsette eller å avbryte et oppdrag?

4. **Om å forebygge over-engasjement i en redningsorganisasjon**
    a. Hva gjør dere for å unngå over-engasjement?
    b. Hva tror dere vil være mest virksomt med tanke på å unngå over-engasjement?

5. **Om over-engasjement og læring**
    a. Er over-engasjement et tema under debriefing?
    b. Er det mulig å gjenkjenne og bryte med over-engasjement mens det pågår – eller lar det seg bare evaluere i etterkant (etterpåklokskap)?
    c. Er over-engasjement "smittsomt"?
    d. Er over-engasjement et tema i opplæring og trening?

Appendix B

Approval to use police logs for information.

POLITIET
POLITIDIREKTORATET

Albert Lunde
Sognefjellsvegen 351
2686 LOM

NATIONAL POLICE DIRECTORATE

Deres referanse:	Vår referanse:	Sted, Dato
	201501209-6 501	Oslo, 18.12.2017

SØKNAD OM TILLATELSE TIL Å BRUKE PO-LOGGER SOM INFORMASJONSKILDE

Det vises til brev av 30.08.2017 vedrørende søknad om tillatelse til å bruke PO-logger som informasjonskilde i anledning pågående Phd-prosjekt om risikostyring i skredredningstjenesten.

Politidirektoratet finner på bakgrunn av **de samme vurderinger og vilkår gitt i vårt brev av 10.04.2015,** å kunne innvilge innsyn i samme grad for Phd-prosjektet som for masterstudien. Det vises i sin helhet til brev av 10.04.2015.

Det er ikke anledning til å gi en generell tillatelse som er uavgrenset på tid til innsyn i PO-logger. Innsyn kan gis for en avgrenset periode. Politiet kan derimot bruke PO-loggene ved tjenstlig behov.

Med hilsen

Heidi Toward
Seniorrådgiver

Kopi til
albert.lunde@uis.no

Politidirektoratet

Post: Postboks 8051 Dep., 0031 Oslo
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www.politi.no

Appendix C

Declaration of confidentiality regarding information from the Joint Rescue Coordination Centres

Hovedredningssentralen Sør-Norge

TAUSHETSERKLÆRING

Jeg forplikter meg til å bevare tausheten om opplysninger og personlige forhold jeg skulle bli kjent med i forbindelse med min undersøkelse av data relatert til skredhendelser, registrert ved Hovedredningssentralen Sør-Norge.

Heller ikke vil jeg gjøre bruk av slike opplysninger i ervervsvirksomhet.

Jeg er klar over at reglene om taushetsplikt også gjelder etter at jeg har avsluttet arbeidet.

Jeg er videre klar over at jeg ved å bryte taushetsplikten kan pådra meg straffeansvar etter den alminnelige borgelige straffelov § 121 om taushetsplikt.

§ 121. Den som forsettlig eller grovt uaktsomt krenker taushetsplikt som i henhold til lovbestemmelse eller gyldig instruks følger av hans tjeneste eller arbeid for statlig eller kommunalt organ, straffes med bøter eller fengsel inntil 6 måneder.
Begår han taushetsbrudd i den hensikt å tilvende seg eller andre en uberettiget vinning eller utnytter han i slik hensikt på annen måte opplysninger som er belagt med taushetsplikt, kan fengsel inntil 3 år anvendes.
Denne bestemmelse rammer også taushetsbrudd m.m. etter at vedkommende har avsluttet tjenesten eller arbeidet.

Albert Lunde

Dato Fornavn og etternavn Fødsel-og personnr.

Et eksemplar beholdes og et signert eksemplar sendes Hovedredningssentralen.

Postadresse Flyplassveien 190 4050 Sola
Besøksadresse Flyplassveien 190 4050 Sola
Telefon (+47)51517000 (+47)51646000 **E-post:** post@jrcc-stavanger.no
Telefax (+47) 51652334 (ops) (+47) 51646008 (adm) **Foretaksnr:** 971513756
Telex (+56)33103