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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. The rescue system is regulated and operated through instructions and guidelines that are based on critical assumptions. We designed the study to challenge critical assumptions in the organized complex rescue system using experiences from operational experts. In two seminars the experts conducted a systemic safety analysis based on *the "Systems-Theoretic Accident Model and Processes"* (STAMP) approach and the *"Systems-Theoretic Process Analysis"* (STPA) technique, deriving goals, hazards, requirements, constraints, a safety control structure and unsafe control actions. The gap analysis revealed that both dispatchers and emergency services are commonly not provided with the recommended training and basic avalanche safety equipment. The causal analysis provided common explanations of recurrent unsafe control actions, allowing plausible accident scenarios to be identified. This study supports a recommendation that the safety control structure of the Norwegian avalanche rescue service should be operationalized in accordance with assumptions and requirements. 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.

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, it was 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. It is 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. A more recent accident happened in a mountain pass near Bahçesaray in Turkey on the 4th and 5th February 2020, when a secondary avalanche killed multiple rescuers during a road related avalanche rescue operation.

Even in successful operations, evaluations may show that rescuers responded in conditions deemed to be too risky for personnel to attempt a rescue effort (Ash & Smallman, 2008). In general rescuers face risks in missions and most first responders understand risk as their exposure to dangerous situations (***Rake & Njå, 2009). Rescue attempts in extreme situations challenge the rescuers ability to strike a balance between tending to victims and staying safe. Depending on how they perceive the situation and the context in which they operate, the rescuers are susceptible to overcommit, i.e. "situations in which rescuers make themselves vulnerable by committing more than is feasible, desirable, expected, recommended, or compellingly necessary" (Lunde and Braut, 2019a; 2019b). Organizational factors like training and preparedness, standard procedures, communication and flow of information were identified by air rescue personnel to prevent overcommitment (Lunde

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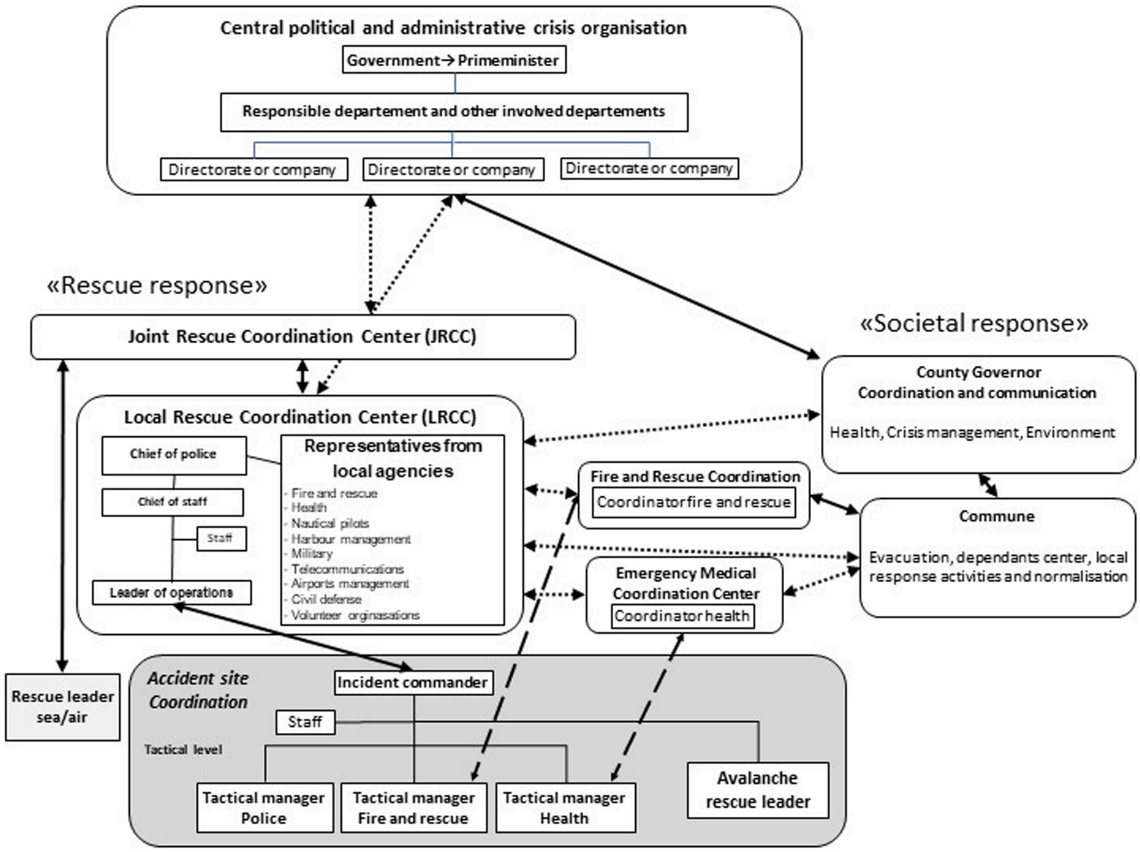

Fig. 1. The design and structure of the Norwegian rescue service.

and Braut, 2019a; 2019b).

1.1. Performance requirements

By design and through incremental development, the rescue service aims for efficiency in their life saving operations, but within certain system level constraints, i.e. "acceptable ways the system or organization can achieve the mission goals" (Leveson, 2011, p. 11). In extreme cases, this could imply that the rescue response is halted. The overall performance, therefore, results from the ability of the rescue service to balance efficiency and safety.

In the avalanche rescue service, a major system safety requirement is that rescuers shall not be dangerously exposed in avalanche terrain. 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 (Lunde & Kristensen, 2013; Lunde & Njå, 2019) 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? Contextual variabilities refer to avalanche locations, environmental conditions, available rescue services, victims involved and available knowledge in the earliest phases of the crisis. In the study reported we wanted to challenge the Norwegian avalanche rescue operations system, based on governing rules, manuals and procedures against practices observed the last twenty years. Historical data and risk assessments of Norwegian rescue missions was part of the underlying knowledge albeit reported elsewhere (Lunde & Kristensen, 2013; Lunde & Njå, 2019). However, in this study we took a design science perspective (Abrahamsson, 2009; Bjelland, 2013; Checkland, 1989; Jackson, 1982; March & Smith, 1995) on the rescue system. How were the normative premises and assumptions laid down for the avalanche rescue system adapted to resolve the practical rescue challenges? Could we find evidence on a structure that showed a *reflective conversation with the situation* (Schön, 1991, p. 79). We sought tacit knowledge from rescue missions, to reveal how practices met the norms. Thus, we retrieved experiences from experts involved in the services.

1.2. Systems safety and major issues

In her approach to safety engineering, Nancy Leveson (2011) departs from traditional risk assessments and component failure thinking as a basis for safe operations. Her ideas on systems safety are developments from Jens Rasmussen's multilevel analysis (***Rasmussen, 1998; Rasmussen & Svedung, 2000) combined with challenges of organisational complexity. The ideas of foundational systems theory contain emergence, hierarchy, communication and control as prominent features. Safety is considered a dynamic control problem. Leveson recommends that organizations establish objectives, requirements and constraints to avoid increased risk levels. Leveson's framework represents a major change in the mind set of safety managers, from advocating compliance-based safety towards active resilience-oriented safety work. The safety control structures are triggers for the rescuers and system controllers to assess and reassess the situation on a continuous basis to maintain the rescue missions within safe boundaries.

The System-Theoretic Accident Model and Processes (STAMP) approach views the 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)

When considering safety as a property emerging from the rescue system as a whole (Leveson, 2011), assessing rescuer safety without examining the context in which the rescuers operate is meaningless. The rescuer's decision making in the front end is framed by the information acquired by the rescue system from the rescue environment (Endsley, 1995). So, the initial assessment of the rescue situation, made by the coordination centres receiving emergency calls, could be vital in providing rescuers with an optimal situation awareness, and to avoid overcommitment (Lunde and Braut, 2019a; 2019b). The order in which the rescuers receive information may also affect decision making (Perrin et al., 2001), indicating that initial control activities linked to avalanche risk assessment is not to be neglected.

In this holistic perspective, we wanted to investigate how undesirable incidents in the Norwegian avalanche rescue service might occur because safety constraints are not properly identified and enforced through active controls (Leveson, 2011, pp. 76-77). Consequently, we adopted the STAMP approach to evaluate the performance of the Norwegian snow avalanche rescue system. The study aims were:

- To reveal the underlying mindset in the avalanche rescue service and evaluate whether the system safety approach could be recognized.
- To challenge the current rules and norms as basis for the rescue services.
- To identify safety control structures, constraints, deviations and weaknesses.
- To evaluate the applicability of the STAMP approach and STPA technique in a system safety analysis of the Norwegian avalanche rescue system.

1.3. The Norwegian snow avalanche rescue system

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, located 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 increase in separate control loops as one gets closer to the accident site (Fig. 1).

The Norwegian avalanche rescue service is an organized complex system. The system is governed by instructions (Regjeringen, 2015), procedures and guidelines (NRR, 2012). Distress calls are normally received by 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. In emergencies requiring coordination of extra-ordinary resources, the JRCC must be notified without hesitation (Regjeringen, 2015). 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.

2. Methodology

2.1. Study design

The study was designed to identify how the operational behaviour of the avalanche rescue system contribute to undesirable incidents; situations where rescuers end up dangerously exposed in avalanche runout zones. In two seminars at the Centre for Societal Safety in Rogaland, Norway, a group of experts discussed various aspects of safety in Norwegian avalanche rescue operations in a cross-case strategy of analysis (Khan & VanWynsberghe, 2008). The discussions were based on three real rescue operations:

- Avalanche hitting a road in Gyadalen, Rogaland – South-western part, 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 – North of Norway, 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 – Western part, 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. The skier was promptly located by his companions but died shortly after the arrival of the rescue resources.

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.

1. Conduct a preliminary Hazard Analysis to identify hazards, constraints and requirements.
2. Model the safety control structure.
3. Conduct a gap analysis by mapping requirements to responsibilities.
4. Conduct a hazard analysis using the STPA technique, step 1.
5. Conduct a causal analysis using the STPA technique, step 2.
6. Identify findings and offer recommendations.

The experts had no prior training in STAMP-based safety analysis. The moderator (the first author) started by introducing the group to the STAMP methodology and the three cases, before inviting the experts to present their views on hazards and control in Norwegian avalanche rescue operations. The first seminar focused on a preliminary hazard analysis and the safety control structure of the Norwegian avalanche rescue service. The second seminar was a stepwise and detailed causal analysis, allowing accident scenarios to be created.

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

1:. Identify goals, hazards, requirements, and constraints related to the activities of the Norwegian avalanche rescue service.
2:. Derive the safety control structure of the Norwegian avalanche rescue service.
3:. Identify recurrent and typical unsafe control actions in the Norwegian avalanche rescue system.

A fourth aim was to evaluate STAMP and STPA as methods for analysing risk and safety in the Norwegian avalanche rescue service.

2.2. Selection of experts

The avalanche rescue system in Norway is a relatively small and transparent community, thus we organized the selection of experts from the major enterprises involved in typical major avalanche rescue missions. By way of nonprobability, purposive, maximum variation, expert sampling (Etikan et al., 2016), we approached 15 experts, of which nine experts turned down the request to participate. There was an element of randomness in this selection, since the final group consisted of those individuals from an initial pool of experts who had time and opportunity to participate in the study. The age of the 6 remaining participants was between 35 and 65 years. The length of service in rescue work, in various positions, ranged between 5 and 40 years. One of the experts was based in North Norway, whereas the remaining five was resident in South Norway. In addition, the participants brought professional experience from previous employments around the country.

The experts had prominent roles in their enterprises and represented more than 100 years of experiences with rescue work. All experts were acquaintances of the first author, who has been a volunteer member of mountain rescue organizations for 40 years and has served in the police for approx. 30 years. The second author has previously conducted a study of emergency preparedness and learning in a major regional avalanche rescue group in Norway.

During the performance analyses, all management levels of the avalanche rescue system were represented, apart from the LRCC. An incident commander (IC) from the police answered questions related to the tasks and responsibilities of the LRCC. 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.

2.3. Material

The seminars took place in November 2017 and February 2018. Each seminar lasted 6–7 h. The data collection resembled focus group interviews through the hazid-process, *"to explore specific topics, and individuals' views and experiences, through group interaction"* (Litosseliti, 2003, p. 1). All experiences and views presented at the seminars were checked against and aligned to the relevant incident reports available in the JRCC's Search and Rescue Application System (SARA). In both seminars, the moderator guided the discussion to cover the necessary steps of the STAMP approach (Leveson, 2011, p. 233). The level of detail of analysis corresponded to what could be identified at the normal hierarchical levels in the rescue service.

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 preliminary version of the safety control structure was modelled by the first author, based on regulations presented in the Plan of Organization for the Norwegian Rescue Service (Regjeringen, 2015), The Norwegian Police Act (Regjeringen, 1995 Nr. 16), Handbook for the Norwegian Rescue Service, and Guidelines for avalanche rescue (NRR, 2012). Thereafter, the experts offered their input to structural design, and the specific control actions and feedback of the various control loops, related to their line of work. This was an ongoing effort during both the first and the second seminar.

We tape-recorded both seminars to support transcription and summary. The material was transcribed immediately after the interviews, and the electronic sound files were promptly 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 member checking, to enhance credibility and trustworthiness (2008). All replies and comments from the experts were included in the final reports. The two reports, each containing approx. 16 000 words, then formed the basis for further discussions and analyses.

2.4. Analysis

To analyse the content of the seminar reports, we applied an approach resembling systematic text condensation (Malterud, 2012). This normally implies starting from the themes of an interview guide, to define relevant categories and meaningful keywords. In this analysis, the categories were pre-defined by our choice to apply the STAMP approach. Since the rescue experts were unacquainted with the STAMP approach they did not communicate in typical "STAMP terms". Consequently, in the written report from the first seminar, all statements made by the seminar participants were categorized according to STAMP terminology (Leveson, 2011, pp. 89-102 and 467–468), e.g. goals, hazards, loss events, requirements, constraints, controller, unsafe control action and scenarios. This was done by colour-coding phrases which were of similar categories and keywords, as illustrated in this excerpt from the original seminar report:

NN commented: A road maintenance worker was clearing avalanche debris from the road, in an area with widespread avalanching. NN asked: Why was he not stopped? NN replied that there is a better cooperation with the road authorities today, and now is the right time to formally include road maintenance personnel in the rescue organization, to allow them the benefit of risk assessments and safety information. NN added that the contractor had a GPS system in the truck, and it was clearly high avalanche danger. Why does no one monitor the situation, and stop road maintenance personnel from entering avalanche danger zones?"

Colour key: .... = System hazard, ... = Constraint, ... = Control action, ... = Feedback, ... = Controller, ... = Actuator, ... = Unsafe control action, ... = Safety control structure, ... = Sensor.

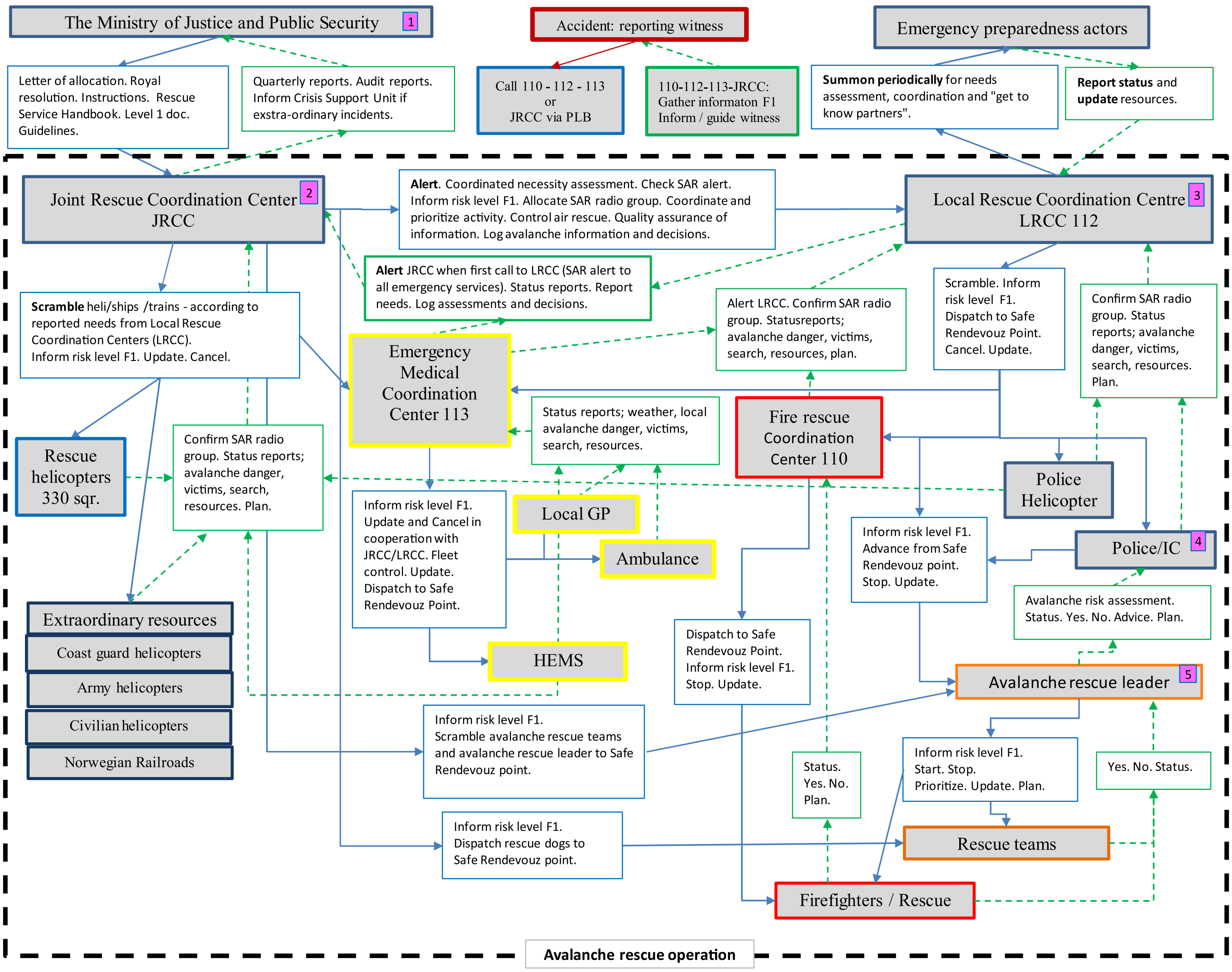

Fig. 2. Safety control structure of the Norwegian avalanche rescue system. The surrounding black dotted rectangle indicates which controllers and activities are involved in managing avalanche rescue operations. Grey boxes: Controllers. Blue continuous arrows: Control activities. Green dotted arrows: Feedback. Abbreviations: IC: Incident commander; HEMS: Helicopter Emergency Medical Service; GP: General practitioner / medical doctor; F1: Filter 1 in a stepwise risk assessment (Kristensen et al., 2007); JRCC: Joint Rescue Coordination Centre; LRCC: Local rescue coordination centre; 110, 112 and 113 are phone numbers that are available to the public to report avalanche accidents; PLB: Personal locator beacon. The pink numbered boxes indicate hierarchical levels of command in the rescue service.

In this approach, all statements made during the discussions were used as a part of the analysis, irrespective of chronology or topic in question. The result was a collection of STAMP related categories, key words, control actions and feedback which was relevant to safe avalanche rescue performance.

The second seminar was dedicated to identifying and explaining unsafe control actions that could lead to rescuers being hit by new avalanches during rescue operations. Tables and figures related to the STPA technique (like the figures and tables in this article) were presented on screen to support the discussion and ensure a structured approach. Specifically, in STPA step 1, we applied the four STPA control action modes presented by Leveson (2011) and Leveson and Thomas (2018) to identify unsafe control actions:

1 Not providing the control action leads to a hazard.
2 Providing the control action leads to a hazard.
3 Providing a potentially safe control action but too early, too late, or in the wrong order
4 The (continuous) control action lasts too long or is stopped too soon

This part of the STPA analysis aimed to identify both "(1) basic inadequacies in the way individual components in the control structure fulfil their responsibilities and (2) risks involved in the coordination of activities and decision making that can lead to unintended interactions and consequences" (Leveson, 2011, p. 235).

In STPA step 2, the experts offered their opinions on why the unsafe control actions occurred. In Nancy Levesons terms, this is called identification of loss scenarios. "A loss scenario describes the causal factors that can lead to the unsafe control actions and to hazards" (Leveson & Thomas, 2018, p. 42). As the analysis progressed from the initial introduction of the technique, the findings offered by the group of experts were added directly to the illustrations on screen, later to be included in the seminar report.

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 the appendix. Some of the findings has already been implemented in the revised version of the Norwegian national guidelines for avalanche rescue. In this section, we concentrate

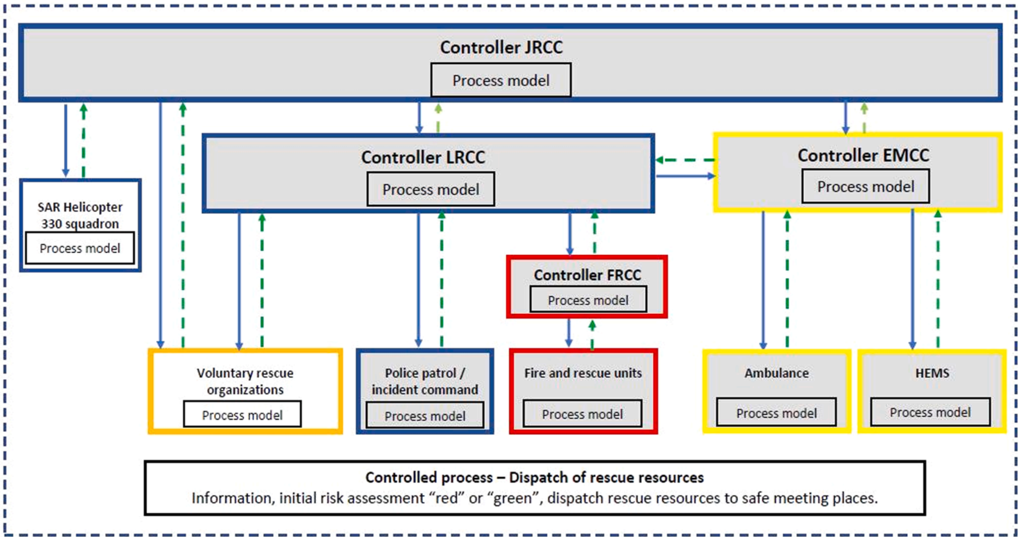

Fig. 3. Controllers and control loops involved in dispatch of avalanche rescue resources. Blue arrows indicate control actions and green arrows indicate feedback loops. Initial risk assessment "red" or "green" in the bottom box refers to the initial conclusion and framing of the mission; "red" is considered 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.

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.

Fig. 2 represents the experts' understanding and presentation of the structure and command system of the Norwegian avalanche rescue service, and which controllers and actuators are involved in avalanche rescue operations. The presented structure contains five main managerial levels on both operational (coordination centres) and tactical levels (accident site commander / police and avalanche rescue leader). 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.

Two control activities are considered 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 Fig. 3. The content of the process models involved in the structure were determined by the functional design of the rescue service, documented in plans and handbooks (Regjeringen, 2015; 2018). From this structure and the process models, it was possible to detect relevant causal scenarios (Leveson, 2011, p. 221).

We notice from Figs. 2 and 3 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 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 (1 1 0), LRCC (1 1 2), EMCC (1 1 3) 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 (see appendix), the analysis group discussed whether any of the requirements are not put into action (Leveson, 2011, p. 232). Important points to consider in the gap analysis 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 of the gap analysis was that important controllers at the LRCC and the EMCC, and frequent first responders from the emergency services, are not provided with the recommended training and equipment for avalanche rescue (NRR, 2012; Van Tilburg et al., 2017). In contrast, personnel at the JRCCs attend the same qualifying courses as members of the volunteer mountain rescue organizations. The experts pointed to specific and detailed training on the avalanche rescue system, rescue techniques and procedures as a prerequisite for safe rescue performance. Also, inter- and intra-organizational inconsistencies in training standards may contribute to variability in avalanche rescue performance.

3.1.2. *Coordination challenges*

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

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

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. See further comments in the Discussion section.

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 Fig. 4, 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. Fig. 4 shows the controllers, control loops and possible control flaws involved in the dispatch of rescue resources.

From Fig. 4 we may identify plausible scenarios that demonstrate lack of control during dispatch of avalanche rescuers. One scenario is that the dispatch centre does not give sufficient priority to avalanche emergency preparedness (insufficient preparations); the controller wrongly believes that all rescue resources on the provided callout list (control algorithm) are competent and equipped (flawed process model); and the responding rescue units do not declare their limitations with respect to training and safety equipment (insufficient feedback).

Another scenario might be that the various dispatch centres respond schematically to the avalanche emergency (flawed control algorithm); uncoordinated dispatch of rescuers causing an autonomous response; dispatchers receive no information about progress and order of arrival of rescue units (insufficient feedback). This results in a “first come – first served” situation, where inexperienced and unequipped rescuers end up as first responders in a dangerous rescue environment.

Overall, these scenarios point to incongruence between the intentional design and the function of the safety control structure.

4. Discussion

To our knowledge, this is the first systems-theoretic analysis of avalanche rescue performance. The focus of this study was the organizational components of the safety control structure of the Norwegian avalanche rescue system, seeking to reveal how inadequate control of operations could lead to undesirable incidents. The question of how a

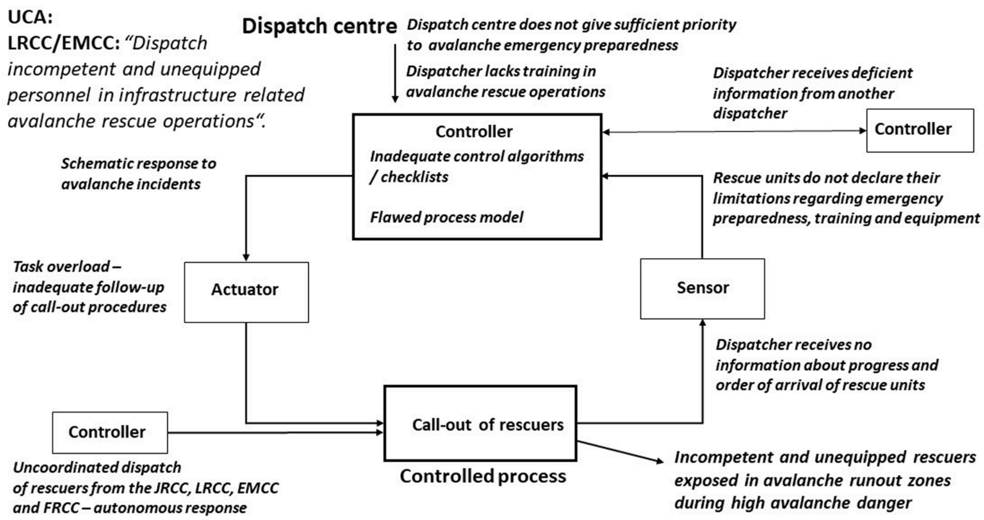

Fig. 4. Control flaws related to the unsafe control actions (UCA): *"Dispatch incompetent and unequipped personnel in infrastructure related avalanche rescue operations"*. The figure is based on the control loop presented in (Leveson, 2013; Leveson & Thomas, 2018) and (Thomas, 2013). Abbreviations: JRCC: Joint Rescue Coordination Centre; LRCC: Local Rescue Coordination Centre; EMCC: Emergency Medical Coordination Centre; FRCC: Fire and Rescue Coordination Centre.

specific design of a rescue service might affect its rescue performance has not previously been debated. This study is not a complementary explanation of all historic accidents in avalanche rescue operations, but the findings point to common weaknesses in the design and operationalization of safety control structures. In this sense it questions whether the form and function serve the purpose of efficiency and safety in avalanche rescue operations. Given that these operations follows the basic principles laid down in the Plan of organization for the Norwegian rescue service (Regjeringen, 2015), relevant findings might also apply to other onshore rescue operations.

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.

Both the Norwegian *"National Guidelines for Avalanche Rescue Operations"* (NRR, 2012), and Van Tilburgh's guidelines (2017) for prevention and management of avalanche and non-avalanche snow burial accidents, 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 challenges

The safety control structures in Figs. 2 and 3 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 challenge 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, a new rule has been introduced to ensure better communication between emergency call centres. This is to ensure 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 the inherent variability in the avalanche rescue system gives infinite 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 and Braut, 2019a; 2019b) 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. Operational risk may require a range of ad hoc approaches that fall outside prescriptions. In fact, general and well-documented injunctions may not make any real contribution to the safety of rescuers who are 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, and amongst the objections for not applying systemic accident analysis are the comprehensive training requirements. E.g. Underwood et al.'s (2016) experience was that the STAMP analysis process was complicated and hard to understand. We found that Leveson's approach resembles how the rescue services comprehend the rescue system, albeit not analysing it as such. 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 participantś 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 modelling, in which the sub-categories of scenarios follow a logical structure to describe how unsafe control actions are created. The sub-categories can later be mapped into a control process loop, as shown in Fig. 4 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 of 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 systemic accident analysis 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 systemic accident analysis 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.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Goals, hazards, requirements and constraints in the Norwegian avalanche rescue service

System goal: To provide safe and efficient rescue efforts in all conditions.

Loss events to avoid are:

1 Rescuers are caught in secondary or neighbouring avalanches in the area of operations.
2 Avalanche victims die or end up seriously injured due to wrong disposition of rescue resources.

System hazards:

<u>Hazard number 1</u>: Rescuers are exposed in potential avalanche runout zones during avalanche danger levels 3–5, when naturally released avalanches are imminent.

<u>Hazard number 2</u>: Avalanche victims are not granted the best possible rescue efforts.

Subdivision of hazard number 1:

Competency

- Lack of competence and experience in road maintenance and rescue personnel.
- Emergency responders without adequate training and safety equipment are dispatched and go directly to accident sites that may be threatened by new avalanches.
- Rescue unit leaders lack competence in the assessment of avalanche emergency situations.
- The competence level in the first responding volunteer rescuers is variable.
- Lack of compliance with requirements to competence in rescuers who respond to avalanche accidents.
- Dispatchers lack training and experience in handling avalanche rescue operations.

Commitment

- Over-commitment is common.
- The risk tolerance level is generally too high.
- Organizational over-commitment is frequent.

Management of operations

- Dispatch is not situation specific – schematic response to all reports of avalanche accidents.
- Deficient safety focus in the alert and dispatch phase.
- Control actions related to safety management are absent or "outsourced" to frontline rescuers.
- Deficient information to first responding rescue units regarding avalanche danger on roads and in the area of rescue operations.
- Deficient and conflicting coordination of rescue units
- Rescuers are not equipped with GPS sensors to monitor their position en route to avalanche accidents.
- Lack of standardization of response across dispatch centres and rescue units.
- No routine dispatch of snow safety specialists in infrastructure related avalanche rescue operations.

Specific police rescue management hazards:

- The police are not giving enough priority to (avalanche) rescue preparedness.
- The police demonstrate a lack of standards and systems in avalanche rescue work.
- The police demonstrate a lack of specific and relevant training of dispatchers at the LRCC.
- Police Incident Commanders and police officers with no training, experience or safety equipment are first responders and managers of avalanche rescue operations.
- Police officers lack training and safety equipment for practical avalanche rescue work.
- Police rescue response is variable and reliant on individually acquired knowledge.

Subdivision of hazard number 2:

Competency

- The rescue operation is wrongly halted due to a deficient avalanche risk assessment.

Commitment

- The rescue operation is wrongly halted due to a too conservative and over-cautious approach.

Management of operations

- Patients do not get the right treatment at the right place at the right time because medical personnel are systematically and unnecessarily kept waiting or detoured to link up with volunteer rescuers.

System requirements

To prevent the hazards from occurring, the following system requirements need to be incorporated:

Emergency preparedness:

- The police must assess the avalanche emergency preparedness in their own region and make appointments with relevant actors (including police units) about the necessary requirements for a safe rescue response.

- The police must gather all rescue organizations to meetings and rescue exercises at least two times every year.
- The police and/or the joint rescue coordination centres must initiate a formal evaluation of all avalanche rescue operations and report findings via the JRCC SAR-report-system.
- All avalanche rescue plans, procedures and checklists must comply with the national guidelines for avalanche rescue.
- All rescue personnel involved in avalanche rescue response must comply with the required minimum of avalanche rescue training.
- Rescuers responding to incidents in avalanche terrain must be equipped with personal GPS tracking systems and avalanche rescue equipment.
- Dispatch routines must ensure a speedy and safe provision of pre-hospital emergency medical personnel.

During rescue operations:

- The JRCC must be notified immediately about avalanche incidents.
- Dispatchers must collect all available information about the avalanche victim, the situation and avalanche risk in the area of operations.
- Dispatch information must include a preliminary assessment of avalanche risk in the area of operations.
- The JRCC are responsible for the coordination of air rescue resources.
- In cases of infrastructure related avalanche emergencies, a trained snow safety specialist must be called out immediately to assist with avalanche risk assessments.
- Rescue units must mobilize only qualified, trained and adequately equipped personnel.
- Rescue unit leaders must report any limitations regarding rescue personnel and equipment to the LRCC.
- Rescue management on all levels must assess, decide on and report whether an immediate rescue response is necessary, feasible and safe.
- An avalanche rescue leader must be called out in the initial phase of a rescue operation.
- In avalanche danger levels 3–5, responding rescuers must be directed to stop at safe meeting places. Further advancement should only take place after a thorough and qualified avalanche risk assessment.
- Prior to advancing into avalanche terrain, all rescue units must assess, select and report a safe route.
- All rescue personnel offer continuous feedback about the situation and the avalanche risk in the area of operations.
- Prehospital emergency medical personnel must respond swiftly and without unnecessary delay to assist avalanche victims.
- Rescue management at all levels must ensure that rescue and safety equipment is made available to all responding rescue units.

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