



Department of Psychology

Why is it safe – enough?

Decision-making in avalanche terrain

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I. Acknowledgement

It all started when I was on my first ski trip to the Alps as a kid. Frankly, it did not start too well. The skies were long, the lift was scary, and the slopes felt very steep. But, with my mother's relentless effort, I slowly began to master the art of skiing. One winter in my mid-teens, I spent a winter in the Alps and was introduced to alpine ski touring. Soon I spent all my time in the mountains skiing with friends. One of my friends had lots of experience and even had some training through the Alpine Club. He taught me some basic avalanche assessment and companion rescue, and off we went on our adventures. I remember he used to offer me the first track on those steep slopes. At that time, I thought it was a very generous gesture. Little did I know that the avalanche is triggered by the first person that enters the slope in most cases. In retrospect, my friend used a clever strategy. Despite his experience and knowledge, he could not be certain that the slope would not avalanche, so he used a test pilot.

My passion for mountains and skiing eventually lead me to become a professional mountain guide. During my guide training, I met the legendary Nils Faarlund and the Norwegian mountain guide community. The Norwegian "friluftsliv" tradition heavily influenced the Norwegian approach to avalanche decision-making at that time. It would take another thesis to explain the profound influence this has had on backcountry skiing in Norway. Briefly summarized, Norway's focus was on understanding snow and generally avoiding avalanche terrain on layered winter snow. This stood in sharp contrast to the alpine ski touring culture and risk-calculation approach that emerged in the Alps. I was puzzled. How could two cultures differ so much in how they understand and cope with the same problem? I spent two years at the Norwegian university of sports, trying to understand this. During this period, I met Swiss mountain guide Werner Munter, the developer of the reduction method, and the late German mountain guide Martin Engler who created the snow-card and factoren check. Inspired by our discussions and their written work, I wrote a master thesis implementing their thoughts in a Norwegian setting. A few years later, I wrote the first book on avalanches in Norwegian that targeted those who wanted to ski in avalanche terrain. The book caused a lot of fuss and revealed major contradictions between those in favour of the traditional approach and those who looked to the Alps and North America for inspiration. Years went by, I was guiding and teaching full time. Practicing decision-making in avalanche terrain and teaching others to do it the same way as me. Looking back, it is interesting for me to reflect on the difference between what I taught and believed in then, compared to what I practice today.

In 2009 The Norwegian Water Resources and Energy Directorate (NVE) was assigned the responsibility for avalanches on a governmental level. I applied for a job at NVE and got the opportunity to be a part of the team that eventually launched the Norwegian Avalanche Warning Service (NAWS) in 2013. In my job, I have been involved in a wide range of tasks related to avalanches, from avalanche forecasting and observer training to public avalanche risk communication, emergency assessments, and app development. The NAWS is part of the European Avalanche Warning Services (EAWS) and cooperates with North American warning services. Through this collaboration, I have had the opportunity to discuss with and learn from the world's foremost avalanche experts. My job at NAWS boosted my overall avalanche competence, but it also made me painfully aware of our current knowledge's limitations.

Four years ago, I was asked if I was interested in doing a Ph.D. on avalanche decision-making at the Center for Avalanche Research and Education - UiT The Arctic University of Norway. My superiors at NVE and the management in CARE/UiT had faith in me and agreed to finance a Ph.D. position. Eventually, it became clear that the best supervising capacity for the type of research that I was interested in was found at the Department of Psychology.

In retrospect, I see that I probably did not fully understand what it meant when I said yes to doing a Ph.D. For someone who primarily identifies as a practitioner, learning to do good research has been both exciting and challenging. Nevertheless, starting on my Ph.D., I was very motivated to solve one of the big questions in avalanches: what is the best way to make slope specific decisions in avalanche terrain? I still do not know the answer, but I do have some well-founded ideas now.

Before I start pursuing these ideas, I must thank everyone who has helped me in various ways. Without the effort of others, this Ph.D. would be impossible.

I want to thank the hundred avalanche experts who took part in the study on factors and methods used by experts. It was a comprehensive survey that required effort and patience. Hopefully, each expert had some personal benefit from reflecting on their decision-making in addition to providing me with invaluable data. This study's results have formed the basis for other studies and will do so for future studies.

I also want to thank all the participants at avalanche seminars who took part in our experiments. I hope that we who benefit from their efforts can give something back in the future.

I have been fortunate to have three supervisors that have complemented each other. Gerit Pfuhl, my main supervisor, has the credit for providing a good balance between learning, reflection, and progress all the way. I have always had a feeling that she has an overall plan that I only fully understand in hindsight. Her love for all aspects of science, her ability to acquire new knowledge, and her working capacity are both impressive and truly inspiring. She has a built-in bullshit filter that has proven to be useful in meeting someone who has a lot on his mind. Most of all she has taught me the art of doing quality science and the importance of a stroll.

My second supervisor is Audun Hetland. He has served as an overpressure valve and lifeline at the same time. When things have felt a bit hard to cope with, he has always encouraged and made me refocus. Me being a novice in academia, Audun eventually made me believe that I have the skills to contribute to avalanche research. I have learned a lot from his talent in research communication and his ability to formulate well-worded sentences. I am going to miss our discussions and exchange of ideas.

The third and final supervisor is my boss at NVE, Rune Engeset. It was he who suggested that I should apply for a Ph.D. project in the first place. He probably had more faith in me than I did. Rune has a unique ability to dive into a topic, understand it, and come up with an explanation that makes others understand. His contribution in all phases of my different studies has been invaluable.

I want to thank my colleagues at NVE, who has had to endure a somewhat absent colleague at times. I also want to thank all the skiers, mountain guides, and avalanche experts worldwide who have taken their time to discuss different aspects of avalanche decision-making with me. These meetings may seem insignificant at the time but have been very important.

Finally, I want to thank my family. You did not ask for this. Thanks for putting up with a demanding version of me.

II. Abstract

Few things are as beautiful as snow-covered mountains. Along with this beauty comes a threat – the threat of avalanches. Backcountry recreationalists face this threat whenever they travel in avalanche terrain. To make a qualified decision of whether a particular slope is safe to ski or not is a complex task that can have fatal consequences. This thesis's overall goal is to improve the decision quality of avalanche risk assessments, aiming to reduce avalanche incidents and accidents. Three aspects of avalanche decision-making that are important for decision quality are studied in five separate studies. These aspects are the decision basis, the decision competence, and the decision process.

The core of avalanche decision-making lies in the decision basis, the factors that are assessed, which ultimately lead to a decision to ski or not ski a specific slope. Several decision-making frameworks (DMF) have been developed to structure and aid decision-making in avalanche terrain. A literature review describing the most commonly used DMFs led to identifying the frameworks' assessment factors in Study I. This first-ever comprehensive review of assessment factors is crucial to understand the structure of existing frameworks and makes it possible to compare their decision basis and provides a foundation to improve the decision quality. In Study II, an expert panel revealed a large discrepancy between familiarity with and actual use of the DMFs. The systematic snow-cover diagnosis, an analytical approach, was the only DMF that experts also used in the field. Further, the survey showed that experts use more and emphasize other factors than most DMFs do and provided an insight into which factors are relevant for avalanche risk assessment from an expert opinion. To provide the basis for teaching an analytical approach, over 1200 recreationalists were asked to rate how well they can assess a risk factor and its relevance. A factor's relevance did not depend on avalanche education, but so did how precisely the factor could be assessed. Thus, Study III substantiates that even non-experts could apply analytical, knowledge-based decision-making given the proper education.

Avalanche decision-making is done in phases with an increasing degree of precision from phase to phase. An avalanche forecast provides decision basis elements and serves as the starting point in the decision-making process. Study IV showed that the Norwegian forecast meets the end user's needs and identified ways to improve the information. The fifth study in this thesis studies the influence of frame selection on risk perception and how it affects actions. When using an analytical approach in avalanche decision-making, the user should be

encouraged to ask, "why is it safe?" instead of "why is it dangerous?" because it results in more cautious, conservative judgments.

When asked about their last good decision, people tend to focus on the outcome, not the decision's quality. In an uncertain environment, the best decision does not necessarily lead to a wanted result and vice versa. Improving decision quality is about increasing our chances of good outcomes, not guaranteeing them. This thesis has improved our understanding of the decision-basis for decision-making in avalanche terrain. All existing DMFs follow a structure, which is how the user should ideally make decisions in the developer's opinion. However, future studies on decision-making in avalanche terrain should rather consider how people are able to make decisions.

III. List of papers

Paper I. Landrø, M., Pfuhl, G., Engeset, R., Jackson, M., & Hetland, A.(2020). Avalanche decision-making frameworks: Classification and description of underlying factors. *Cold Regions Science and Technology*, 169, 102903. doi:10.1016/j.coldregions.2019.102903

Paper II. Landrø, M., Hetland, A., Engeset, R., & Pfuhl, G.(2020). Avalanche decision-making frameworks: Factors and methods used by experts. *Cold Regions Science and Technology*, 170, 102897. doi:10.1016/j.coldregions.2019.102897

Paper III. Landrø, M., Engeset, R. & Pfuhl, G (2020). The role of avalanche education in assessing and judging avalanche risk factors. Submitted to the Journal of Arts and Sport Education

Paper IV. Engeset, R. V., Pfuhl, G., Landrø, M., Mannberg, A., & Hetland, A. (2018). Communicating public avalanche warnings – what works? *Natural Hazards and Earth System Sciences*, 18(9), 2537-2559. doi:10.5194/nhess-18-2537-2018

Paper V. Stephensen, M., Schulze, C., Landrø, M., Hendrikx, J. & Hetland, A. (2020). Should I Judge Safety or Danger? Perceived Risk Depends on the Question Frame. *Journal of Experimental Psychology: Applied* doi:10.1037/xap0000354

IV. List of abbreviations

Avalanche Terrain Exposure Scale	ATES
Center for Avalanche Research and Education	CARE
Decision-making framework	DMF
European Avalanche Warning Services	EAWS
International Federation of Mountain Guides Associations	IFMGA
International Snow Science Workshop	ISSW
Klassifisering av snøskredterreng (Classification of Avalanche Terrain)	KAST
Know Before You Go	KBYG
Norsk Fjellsportforum (Norwegian Mountains Sports Forum)	NF
Norwegian Avalanche Warning Service	NAWS
Observational Guidelines and Reporting Standards	OGRS
Reduction Method	RM
Systematic Snow-cover Diagnosis	SSD
The Norwegian Trekking Association	DNT
The Norwegian Water Resources and Energy Directorate	NVE
The Swiss core training team of Snow Sport Avalanche - Accident Prevention	KAT
The Swiss Institute for Snow and Avalanche Research	SLF
Quantitative Reduktionsmethode	QRM
Why is it safe – enough	WISE
Österreichischer Alpenverein (Austrian Alpine Club)	ÖAV

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1 Introduction

Backcountry skiing involves a continuous battle between two conflicting interests: maximally accessible ski terrain versus the desire for maximal safety. The challenge is to balance this to the best possible extent. The following real-life story tries to convey what skiing in steep terrain is all about while at the same time giving a picture of the complexity of decision-making and what is at stake.

The mountain has put on her finest white dress. Deep powder snow is covering all her different features. The sky changes from red and orange to deep blue as the sun rises. It is cold, calm, and the snow is sparkling. To the three skiers breaking trail, it seems like a perfect day to visit this very mountain. Today's destination was decided after consulting the avalanche forecast and a short chat on the phone the day before. All three are skilled skiers who have been skiing in the backcountry for years. They know what good skiing is, and the conditions seem promising. There is no exact plan for where to ski, just different possible options. As they approach the lower parts of the mountain, they get an overview of some relevant alternatives. They decide on a route that starts with a big, open face at the top and ends in a narrow couloir with steep rock walls on both sides in the lower part. None of them have skied this route before, but it looks like a perfect challenge for a skilled skier. A stable old snowpack with half a meter of dry, loose powder on top provides seemingly perfect conditions. The skiers ascend the mountain by moving in a gentler terrain than the route they plan to ski down. Occasionally they stop to enjoy the view and discuss conditions. So far, they have not observed any signs of instability, and they continue as planned. Towards the top, the terrain steepens, and they mount the skis on their backpack. Up here, the snow is more wind affected, making it easy to walk on feet without sinking too deep into the snow. The ascent continues without problems. Perfect timing, the sun just hit this side of the mountain. After a quick break, they are standing on top of their descent, trying to get an overview of the whole route. From here, the upper part looks quite steep and a little scary. Not only is it a no-fall zone. An avalanche release would most likely be fatal. They discuss conditions for a while. Eventually, the first skier puts on his goggles, checks the bindings one last time, and starts skiing the planned descent. To me, the question is not *why* he decides to ski, but on *what basis* he makes his decision.

1.1 Recreational backcountry skiing and avalanche accidents

Backcountry skiing is becoming increasingly popular in mountainous regions in the western world. From being reserved for relatively few enthusiasts, it has become something many skiers want to learn and experience. Avalanche experts agree on this increase of backcountry recreationalists, even if available data confirming it are sparse (Winkler, Fischer, & Techel, 2016; Zweifel, Ruez, & Stucki, 2006). Despite an increase in backcountry recreationalist in the last decade, the number of accidents has not increased correspondingly (CAIS, 2020; NVE, 2020; Techel, Jarry, et al., 2016). Avalanche researchers explain this with improved avalanche prevention measures such as avalanche forecasting, avalanche education (Etter, Meister, Zweifel, & Pielmeier, 2008; D. McClung & Schaerer, 2006), and improved avalanche rescue technology (Brugger et al., 2007; Techel & Zweifel, 2013). However, one should not disregard the fact that a favourable snow cover can significantly limit the number of accidents in a given season. Some avalanche problems, such as persistent weak layers, recur in many accidents but are not as prominent every winter (J. Aasen, 2019; J Aasen, 2020; Techel & Winkler, 2015). Still, on average, 150 people lose their life in avalanches every year in Europe and North America (CAIS, 2020; Techel, Jarry, et al., 2016). The number of near-misses, both registered and unregistered, is much higher (J. Aasen, 2019), indicating considerable potential for severe or fatal accidents. The difference between an avalanche release leading to a fatal accident or a minor incident depends on the size of the avalanche and the location of the victim in relation to the avalanche, and terrain features that might cause severe traumatic injuries on impact (Brugger, Durrer, Adler-Kastner, Falk, & Tschirky, 2001; B. Jamieson & Jones, 2015).

Most recreational avalanche accidents are not random events. They result from someone willingly placing themselves at risk when doing something they love - skiing in the backcountry. They are "accidents of choice". Most recreationalist are aware of the risk they expose themselves to, but some are not (Björk, 2007; Gunn, 2010; Sole, 2008). Even though risk itself is not a motive in any adventure or extreme sport (Brymer, 2010) it is seen as central in creating a challenge (Collins & Collins, 2013). Avalanche terrain is different. Here, risk of avalanches is not tied to the challenge of skiing, but rather an abstract risk that limits a skier's availability of potential terrain to ski. At the same time, it is important to emphasize that avalanche risk does not increase the value of the skier's skiing experience. Skiers do not ski because of the thrilling risk of avalanches. They do it despite the risk. The skiing experience would be just as good, or probably better without it. Skiers choose to ski. By doing

so, they expose themselves to an unwanted risk of avalanches. Besides the physical effort of ascending and descending, a cognitive effort is put into finding great skiing, avoiding avalanches, and making decisions to achieve that. Sometimes decisions lead to an avalanche release. Indeed, in most avalanche accidents, the avalanche is triggered by the victim or someone in the victim's group (D. McClung & Schaerer, 2006; Schweizer & Lütschg, 2000). Hence, available information may have been overlooked, misinterpreted, or not considered (Arnott, 1998; I. McCammon, 2004; D. M. McClung, 2011; Mersch, Trenkwalder, Semmel, & Stopper, 2007).

1.2 Avalanche research

Traditionally avalanche researchers have focused their research on improving our basic understanding of avalanche formation, including fracture propagation and slab avalanche release (J. Gaume & Reuter, 2017; Heierli, 2008; D. M. McClung, 2013; D. M. McClung & Borstad, 2017; van Herwijnen, Schweizer, & Heierli, 2010), slope stability and spatial variability (J. Gaume & Reuter, 2017; J. Gaume et al., 2014; Reuter, Schweizer, & van Herwijnen, 2015; Schweizer, Kronholm, Jamieson, & Birkeland, 2008), comparison of (in)stability tests (Techel, Winkler, Walcher, van Herwijnen, & Schweizer, 2020; Winkler & Schweizer, 2009), slab properties (Schweizer, Reuter, Van Herwijnen, Gauthier, & Jamieson, 2014) or the effect skiers have on the snowpack (Habermann, Schweizer, & Jamieson, 2008; Monti, Gaume, van Herwijnen, & Schweizer, 2016; Schweizer & Lütschg, 2000; Schweizer, McCammon, & Jamieson, 2008). Others have investigated what can be learned from accidents and from analysing recurring avalanche risk factors (Grímsdóttir & McClung, 2006; Schweizer & Lütschg, 2001; Techel, Jarry, et al., 2016; Techel & Zweifel, 2013; Winkler et al., 2016). There is also research that is targeted directly at backcountry skiers, such as suggestions for in field risk calculations (B. Jamieson, Schweizer, J., Shea, C., 2009), methods for analysing the snowpack (I. McCammon & Schweizer, 2002; Reuter & Semmel, 2018; Schweizer & Jamieson, 2007) or how to use field observations to determine avalanche danger (Schweizer, 2010). Although not all findings from avalanche research can be applied directly in the field, practitioners have benefitted from it and improved their ability to make good decisions in avalanche terrain.

In later years there has been an increased recognition of the role of human factors in avalanche decision-making. This has led to studies focusing on other aspects of avalanche decision-making, such as group dynamics (Zweifel, 2015; Zweifel & Haegeli, 2014), risk-

taking behaviour (P. Haegeli, Rupf, & Karlen, 2019; Mannberg, Hendrikx, & Johnson, 2020; Mannberg, Hendrikx, Landrø, & Ahrlund, 2018), cognitive processes (L. Maguire & Percival, 2018; L. M. D. Maguire, 2019) and learning (Adams, 2005a; Conger, 2005; Stewart-Patterson, 2005).

1.3 Concepts and terminology

Next, I will describe relevant concepts and clarify terminology regarding avalanche decision-making. I start with two core concepts from the natural science part, followed by concepts from the social science part of avalanche risk assessment.

1.3.1 Avalanches

An avalanche is a mass of snow (more than 100m³) rapidly moving down an inclined surface a minimum of 50 meters (EAWS). In a recreational setting, avalanches can be divided roughly into two; slab (dry or wet cohesive plate of snow) and loose (dry or wet snow with little or no bonding). Their characteristics differ in terms of how fast the snow stabilises, possibility of remote triggering, typical release zone steepness, release characteristics and destructive force related to size and density. Human triggered loose snow avalanches tend to be released beneath the skier who triggers them, instead of above as slab avalanches often do, making them a lot less dangerous to skiers. One should not underestimate the danger of loose snow avalanches, as they pose a danger if skied into or if they trigger underlying slab avalanches. However, compared to slab avalanches, very few people are killed, and their assessment and management are much easier. Slab avalanches account for nearly all recreational avalanche deaths. Therefore, the focus of this thesis is on the assessment of slab avalanches. Cornice fall avalanches, icefall avalanches, glide avalanches (the entire snowpack glides on the ground), and slush avalanches are also referred to as avalanches. Although they occasionally claim the lives of backcountry recreationalists, especially cornice fall avalanches, the assessment basis of these is not discussed in this thesis.

1.3.2 Avalanche terrain

An avalanche path consists of three components: Starting zone, track, and deposition or runout zone (D. McClung & Schaerer, 2006). Together they are also referred to as avalanche terrain. The term is frequently used in avalanche hazard communication, e.g., "avoid all exposure to avalanche terrain due to current conditions."

A slab avalanche is the result of fracture initiation and following fracture propagation. Given that the slope is steep enough, the overlying slab releases and slides down the slope. All three processes are affected by inclination (Johan Gaume, van Herwijnen, Chambon, Wever, & Schweizer, 2017; D. McClung & Schaerer, 2006; Reiweger & Schweizer, 2010). Not all processes of fracture initiation and fracture propagation are fully understood. For all practical purposes it is sufficient to understand that the steeper the slope, the easier a fracture is initiated, the easier a fracture propagates, and that dry snow will slide when a proportion of the slope is $>25^\circ$. However this low angle is the infrequent lower limit (D. McClung & Schaerer, 2006), and 30° is communicated as the critical angle in the context of training (S. Harvey, Rhyner, & Schweizer, 2012; Munter, 1997; Studerregger, 2016; Tremper, 2001). Most avalanche accidents happen in slopes between 35° and 40° inclination, regardless of the forecasted danger level (S. Harvey, 2002; S. Harvey et al., 2012).

Avalanche terrain is characterized by more than the one-dimensional factor inclination. The avalanche terrain exposure scale (ATES) is a method to communicate the complexities and risks of traveling in avalanche-prone terrain (G. Statham, McMahon, & Tomm, 2006). It classifies terrain into different classes: simple, challenging, and complex. The three classes are determined in a technical model that describes exposure to different terrain elements such as inclination, forest density, terrain traps, and avalanche frequency. Whereas the technical model is primarily reserved for skilled users, the public communication model targets a less skilled audience. The ATES system is an integrated part of the Canadian decision-making framework (DMF), the Avaluator 2.0 (P. Haegeli, 2010). ATES is well suited to teach avalanche terrain fundamentals and basic route finding, and help balance terrain choice, conditions, and competence. The system is currently revised, and a new version is under development, probably with a more fine-meshed classification (Larsen, Hendrikx, Schauer, et al., 2020). Initially a Canadian initiative, ATES has gained popularity also in other countries, especially in Scandinavia. ATES and its Norwegian equivalent KAST are used in guidebooks and actively used as safety measures for avalanche observers in Norway (Landrø, Engeset, Haslestad, Aasen, & Orset. K., 2016). Currently, all avalanche terrain in Norway is mapped using an automated ATES model (Larsen, Hendrikx, Slåtten, & Engeset, 2020).

1.3.3 Decision environment

Throughout the winter, snow settles in layers on the ground. Every snowfall adds a new layer. Wind, radiation, and temperature determine the properties of the layer (e.g., thickness, hardness), how well it bonds to the underlying layer, and how it develops further. Some layers are strong and bond well. Others are weak and can collapse with additional loads, such as a skier. When an overlying layer (slab) buries a weak layer, a weak layer collapse can propagate under the slab. Given terrain steeper than 30 degrees, the slab can release as an avalanche. Roughly speaking, a slab avalanche results from the interaction between a weak layer, slab, terrain, and a trigger. To trigger an avalanche, one must either weaken the strength of the snowpack (e.g., rapid increase in temperature) or increase stress (e.g., new snow or wind loading). When an avalanche is triggered without the interference of people, it is called a *natural* avalanche release. However, in most cases where humans are injured or killed when engaged in recreational activity, they also serve as the trigger. These avalanches are referred to as *human* triggered avalanches.

This is, of course, a very simplistic presentation of the causes and triggers of slab avalanches. Each of the four overall factors; terrain, weather, snowpack and people, consist of a number of underlying factors and the interaction between them is very complex and there is uncertainty associated with their assessment. For example, there is uncertainty associated with inclination measurement (Würtl, 2016), weak layer spatial distribution (J. Gaume et al., 2014; Jürg Schweizer et al., 2008), to mention a few but critical examples. Another striking example of the uncertainty associated with the assessment of snow cover stability can be found in the Canadian Avalanche Association Observational Guidelines and Reporting Standards for Weather, Snowpack and Avalanches (OGRS) (CAA, 2016). Here the word *rule* is used seven times while at the same time indicating that no definitive rule is possible. So, even before we start to include the influence of human factors, it becomes clear that it is impossible to determine avalanche danger with absolute certainty. Thus, it is reasonable to claim that avalanche decision-makers operate in a world of uncertainty.

Fortunately, human triggered avalanches are a quite rare incident in relation to the amount of avalanche terrain that is being covered by backcountry recreationalists every winter. To get caught in an avalanche, one needs to venture in or close to steep enough terrain with the “right” combination of weak layer and overlying slab in the snowpack. This “right” combination prevails only for limited periods and portions of the terrain during a winter. In

general, there is limited or no feedback on how close one was to an avalanche release. Winter backcountry travelers therefore face what is called a wicked learning environment (R. M. Hogarth, Lejarraga, & Soyer, 2015). Repeated experience of non-event feedback can result in a false sense of confidence in assessment skills, and it becomes difficult to develop reliable intuition. It takes considerable amount of experience to develop reliable intuition, which is a privilege mostly reserved for experts. Therefore, most backcountry recreationalists must rely on deliberate reasoning, that may even be in competition with their falsely developed intuition. A study by the DAV-safety research showed that 110 of 120 informants reported a positive feeling of safety after a ski-trip, even though 78% of them did not apply appropriate actions at the critical places of the tour (Mersch et al., 2007).

1.3.4 Decision-making phases

Decision-making in avalanche terrain is structured into three phases; trip planning (regional), route selection (local/visible area), and slope-specific (zonal) decision-making. This approach serves as an increasingly fine-meshed net that allows the user to update and review the decision basis from the previous phases. In the trip planning phase, any local knowledge, information from maps, guidebooks, weather forecasts, the group's composition, and the avalanche forecast forms the basis for deciding which area to visit and what mountain to ski. In the route selection phase, the forecast is verified, information is updated, and the original plan is adjusted or changed. Other factors, such as snowpack information and signs of instability, become relevant. The constant update and information sampling continue in the slope-specific phase where the decision to ski or not is made. Again, other factors, like stopping at safe spots, skiing one-at-a-time, come into play.

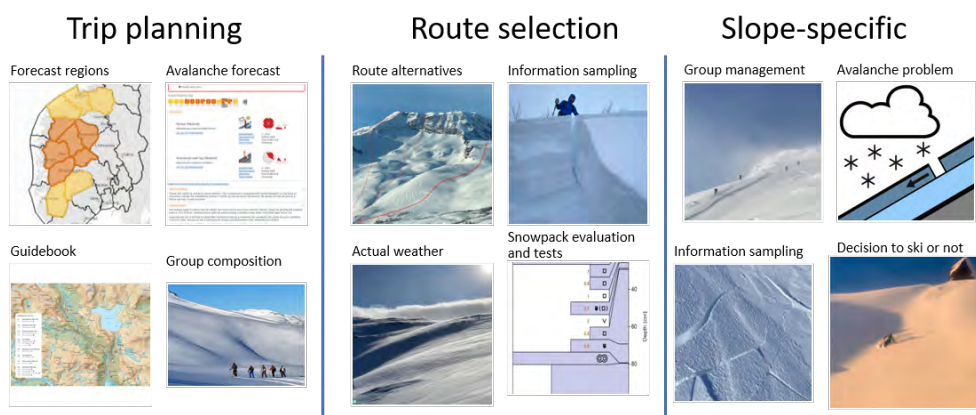


Figure 1 The main elements in each of the three decision-making phases

The 3x3 (3 filter x 3 criteria) by Werner Munter is an example of a structured approach to avalanche decision-making that evaluates a set of factors across three phases (Munter, 1997). The 3x3 is an integrated part of the Reduction method and is often used in combination with other frameworks.

Another more comprehensive alternative is the AIARE Risk Management Framework which operates with the following phases; 1. Prepare (each season), 2. Plan your trip (equals the trip planning phase), 3. Ride safely (equals route selection and slope-specific phase), 4. Debrief the day (AIARE, 2021). In phases 2-3, teamwork is emphasized. Unlike the 3x3, this framework includes both education and evaluation.

1.3.5 Avalanche decision making frameworks

To make a qualified decision of whether a particular slope is safe to ski or not demands assessing a range of factors. To aid this decision, several decision-making frameworks have been developed by avalanche experts. Historically, different checklists in various formats have been available. According to LaChapelle, the earliest checklist is G. Bilgeri's Six Points, which was in use in the 1930s, followed by Atwater's Ten Contributory Factors in the 1950s (LaChapelle, 2005). However, no overall, methodical, and structured approach to avalanche decision-making existed. This changed when Swiss mountain guide Werner Munter introduced the 3x3 in the 1980s, initiating the development of a range of different frameworks (Munter, 1991). At the core is his structure of decision-making into the planning stage, the route selection stage and the slope-specific stage during an outing.

Various terms are used when referring to these aids. English speaking countries use the terms decision aid, method, scheme, or decision tool (P Haegeli, McCammon, Jamieson, Israelson, & Statham, 2006; I. McCammon, 2006; I. McCammon & Hägeli, 2005), whereas aids originating from the German-speaking part of the Alps mainly use decision system or decision strategy (Engler, 2001; S. Harvey et al., 2012; Larcher, 1999; Munter, 1997). This thesis uses the term decision-making framework when referring to all these aids. Framework refers to a basic structure underlying a system used to plan or decide that follows certain overall principles.

Today's decision-making frameworks are explained in avalanche handbooks or folders and taught in avalanche safety courses. To further aid the decision process, most of these methods come with a plastic-coated card or a checklist to take along in the mountains.

Common to all frameworks is that the decisions are based on an assessment of different factors, such as: (1) the physical factors like slope steepness or slope shape, (2) regional danger rating provided by the avalanche forecast, and (3) signs of instability (alarm-signs) like for example shooting cracks, whoop sounds from the snow, assessed in the field, and (4) group size affecting decision making. However, existing frameworks work with simplifications to meet the assumed limited experience and knowledge of the user. Users who have gained some personal experience may start to deviate from the original rules and structure set out by the frameworks. This leads to variations of the original frameworks where exceptions from the basic rules are allowed, and adjustments by the user are applied. Thus, providing a tool to ensure safe travel in avalanche terrain is a difficult task. It is a question about balancing the users desire for maximum enjoyment (amount and kind of terrain that is considered safe to ski by the framework) and the risk of being caught in an avalanche (D. M. McClung, 2002). To avoid this risk altogether, one must avoid avalanche terrain. All other approaches involving travel in avalanche terrain means varying degrees of risk and uncertainty.

Not all existing frameworks work equally well in every situation. A comparison of existing decision frameworks shows that most of them perform poorly at low and moderate avalanche danger and are sensitive to avalanche climate (I. McCammon, Haegeli, P., 2004). The same study also shows that simpler methods appear to be superior to more complex decision methods, similar to studies from other fields, e.g., medicine (Gigerenzer, 2014). Even relatively simple aids can influence the decision-making process in the direction of a more avalanche hazard sensitive behaviour (P. Haegeli, Haider, Longland, & Beardmore, 2009).

All decision-making frameworks have in common that they help recognizing hazard and recommend actions to manage the associated risks. For example, when deciding to ski or not to ski a certain slope, the After-ski method can “restrict” skiing based on steepness and the regional avalanche danger level, whereas the Avaluator combines an avalanche condition score with a terrain characteristic score that results in a recommendation of caution, extra caution or not recommended (Brattlien, 2014; P. Haegeli, 2010). What varies between the different methods is the performance in prevention, mobility, ease of use and utility (I. McCammon, Haegeli, P., 2004). The calculated prevention values of the Avaluator has been criticized for being grossly inflated and giving the users a false sense of confidence in slope stability (Uttl, Kibreab, Kisinger, & Uttl, 2009). This was due to the exclusion of more than

1100 accident reports due to missing values. However, attempts to calculate a preventive value based on avalanche accident statistics face the same challenge due to the inherent biases in the data i.e., sampling bias (only reported accidents) and hindsight bias (available information). Another problem is that it is challenging to test for false negatives (DMF says NO, but the slope is stable and could be skied) and false positives (the DMF says YES, but the slope is unstable and should not be skied). Systematic Snow cover Diagnosis (SSD) is the only framework which has been tested for this, but only in a single study (G. Kronthaler, Mitterer, C., Zenke, B., Lehning, M., 2013).

1.3.6 Probabilistic and analytical avalanche decision-making

Decision-making frameworks fall into two general categories: Probabilistic and Analytical. Munter called his Reduction method probabilistic (Munter, 1997), and since most DMFs are derived from his original method, this is the term used in this thesis. Other terms used are rule-based and knowledge-based systems (I. McCammon & Hægeli, 2005). The term analytical corresponds to knowledge-based decision-making in McCammon and Hægeli's terminology. Most DMFs have components from both approaches.

All frameworks are based on the use of several factors. The difference lies in whether a factor is regarded as a physical factor or a statistical factor. For example, avalanche accident statistics from the Alps show that the majority of avalanche fatalities are located in a northern aspect, so probabilistic frameworks have calculated a risk-score for skiing in the northern aspect (Munter, 1997). An analytical approach, however, regards the aspect as a physical factor, e.g., that it is of importance for snow metamorphism and snow stability due to the effects of solar radiation and temperature. Instead of looking at the northern aspect as having a certain risk-score regardless of the conditions, an analytical approach would rather evaluate how the weather (e.g., temperature and radiation) has affected the snowpack in terms of stability. This is also called process thinking (G. Kronthaler, 2019; G. Kronthaler, Mitterer, C., Zenke, B., Lehning, M., 2013).

Another example are group factors. Statistically, small groups are less exposed to avalanche accidents than larger groups, and a risk score for different group sizes can be calculated (Munter, 1997). An analytical approach would be to take the groups composition (e.g., competence, leadership, communication) into account and adjust trip selection

accordingly. One would also consider available group management possibilities to reduce the load the group exerts on the snow cover.

In an analytical decision-making framework, the overall structure is a sort of open-ended checklist that helps the user structure the decision process and not to overlook important factors or cues. The use presupposes that the user is able to assess the various factors and see these in context. Probabilistic frameworks on the other hand generally require less of the user. Based on avalanche fatality statistics, a probability of triggering an avalanche in a given situation is calculated, and numerical thresholds are used for making go/no-go decisions.

Critics claim that an analytical assessment is a difficult task even for experts and that this type of approach is thus unsuitable for recreationalists (Brattlien, 2014; Munter, 1997). This view is not shared by all avalanche experts. In North America there is generally far more focus on snow knowledge and elements of analytical assessment both in recreational as well as professional avalanche education than is the case in parts of the Alps. This is first and foremost expressed in the methods that are developed and taught in the different countries (Behr & Mersch, 2018; Grady, 2013; P Haegeli et al., 2006; S Harvey & Nigg, 2009; Pichler, 2014). However, even in the German speaking part of the Alps, where the use of probabilistic frameworks has the greatest prevalence, the use of W3-Wer geht wann wohin? (Who goes where when?) and the SSD, shows that analytical methods are used too (G. Kronthaler, 2019; Studeregger, 2016).

1.3.7 Avalanche decision-making factors

All decision-making frameworks build on a selection of factors. These factors are sometimes referred to as avalanche risk factors – factors that contribute to the avalanche danger, such as signs of instability and wind-loading (S. Harvey, Rhyner, Dürr, Schweizer, & Henny, 2018; D. McClung & Schaerer, 2006; Techel, Zweifel, & Winkler, 2015). However, the term is also used on different categories of factors, such as weather factors, snowpack factors, terrain factors and human factors. In this thesis, the term factor is used for all the different "puzzle pieces" underlying the different decision-making frameworks. The factors are thematically grouped into five categories: Snow and avalanche factors (e.g., signs of instability), Snowpack evaluation and stability tests (e.g., weak layer properties and test scores), avalanche forecast factors (e.g., danger level), Group and group management factors (e.g., group size, and stopping at safe spots), and terrain factors (e.g., inclination and terrain

traps). The term factor is used to avoid using different terms when discussing factors within the different categories.

1.3.8 Risk and uncertainty

The term risk, or more precisely, the risk concept, has different meanings in different disciplines. In simple terms, risk is the possibility of something unwanted happening, but several definitions with different focus exist (see i.e., (Aven, 2012; Hertwig, Pleskac, & Pachur, 2019). Within the avalanche domain, the term risk is used far more frequently than uncertainty, and it is often used in combination with the word avalanche (e.g., avalanche risk, avalanche risk management, and avalanche risk assessment). Talking about avalanche accidents, hazardous events with dimensions other than probabilities and outcomes, it makes sense to use the term risk because it addresses the catastrophic potential of an accident. Also, in situations where all possible outcomes and their probabilities are known – as in a lottery, there would be decision-making under risk (Hertwig et al., 2019). A simple probability calculation would be sufficient. Whether the premises for risk calculations are present within the assessment of avalanches, is frequently discussed between avalanche experts. Nevertheless, it has resulted into overall approaches to avalanche decision-making, an analytical and a probabilistic approach.

Whereas risk applies to situations of measurable probability, uncertainty applies to situations where such measurement is impossible. It is characterized by a state of incomplete knowledge and comprises two dimensions (Kozyreva & Hertwig, 2019; Ulkumen, Fox, & Malle, 2016). One dimension is environmental (aleatory) uncertainty. For instance, the weak layer distribution in a snowpack varies over time and space. The other dimension is knowledge-based (epistemic) uncertainty. It stems from limits in available knowledge about a fact and cognitive capabilities. In contrast to the inherent aleatory uncertainty associated with avalanche decision-making, epistemic uncertainty can be reduced with increased knowledge and training.

In addition to these two dimensions of uncertainty, there is a third that applies to avalanche decision-making: Language-based uncertainty. This uncertainty arises because words can have vague or ambiguous meanings. Thus, people use and understand words differently (Burgman, 2016). Within avalanche decision-making, the language-based uncertainty becomes particularly problematic when discussing the likelihood of triggering an avalanche and certainty level in the assessment.

The distinction between risk and uncertainty is essential because it influences how one understands the avalanche decision-making problem and how one decides to approach it.

1.3.9 Avalanche forecast

To provide the public with detailed information about the snowpack and current avalanche situation many countries have avalanche warning services publishing avalanche forecasts, also called bulletins or warnings. An avalanche forecast is a prognosis trying to predict how the snow and avalanche conditions will be in a defined geographical region either later the same day or the next day, depending on publishing policy in each warning service. Production of avalanche forecasts includes two steps. The first step is an assessment of the current situation. The most important sources of information for avalanche forecasters are:

- Field observations provided by observers
- Data from weather stations and snow- and weather models

The second step is making a prognosis. When the avalanche forecaster has an overview of the snow cover's current situation/status and the weather, they can start writing a forecast. That is, to predict how the reported weather will affect the snow cover and the risk of avalanches (Engeset, 2013). In the Norwegian Avalanche Warning Service (NAWS), the forecaster team includes an avalanche meteorologist who makes a weather forecast, especially for the warning regions' mountain areas. Hence, the forecasters have a good starting point for predicting the development of snow and avalanche conditions.

Avalanche forecasts have similar content and use an information pyramid, presenting the most important information, the danger level, first (EAWS). The European forecasting services use the EAWS Matrix to determine the danger level, a function of the probability of avalanche release, distribution of hazardous sites, and avalanche size (EAWS). The danger is expressed in a five-stage scale, ranging from 1-low to 5-very high (EAWS). In North America, a slightly adapted version of this scale is used (G. Statham et al., 2010). The avalanche forecast also provides information on areas where the danger is particularly significant, referred to as avalanche prone locations. These areas (aspect, elevation, and specific terrain features) are described using graphics and text. When writing an avalanche forecast, the forecaster can choose between five different avalanche problems in Europe (EAWS) or eight in North America (G. Statham et al., 2018). A forecast can contain up to three different avalanche problems that are the cause of the avalanche danger in the region,

e.g., persistent weak layer or wind drifted snow. The avalanche problems are expressed using icons. The avalanche risk assessment element is the avalanche warning's summary of factors that affect the avalanche danger and the reasons for choosing the avalanche problem. Finally, the avalanche forecast also contains snowpack information, a general description covering both the snow's layering and the stability and a mountain weather forecast. The NAWS and some other warning services have integrated travel advice aimed at snow sports enthusiasts or special information aimed at preparedness authorities in their forecasts. These advices are based on the current danger level and avalanche problem.

The avalanche forecast applies for a region with a minimum size of 100 square kilometres (Nairz, 2010). It is an excellent starting point for trip planning but cannot fully answer the backcountry recreationalists question of whether it is safe to ski a specific slope or not. It is worth emphasizing that a forecast is based on the information available at any given time and that, for example, differences between the forecasted weather and actual weather or local differences may lead to the forecast not being correct. Verification and harmonisation of the forecasted danger level is no easy task (Techel, Dürr, & Schweizer, 2016; Techel, Müller, & Schweizer, 2020). Nevertheless, verification of predicted avalanche danger level proposes a score between 60%-80% (Föhn, 1995; B. Jamieson, Campbell, & Jones, 2008; Schweizer, Kronholm, & Wiesinger, 2003). Given these limitations of the forecast, backcountry recreationalist must make independent assessments based on field observations and base their decisions on these.

1.3.10 Human factors

As the story in the introduction shows, decision-making in avalanche terrain is about much more than snow physics. It involves group decision-making, communication, feelings, motivation, cognitive capacity, handling uncertainty, previous experiences, and knowledge acquisition, to mention a few issues. In recent years one has begun to take an interest in the decision-maker. The avalanche community refers to this as the human factor (I. McCammon, 2009). Human factors are now an integrated part of many avalanche education initiatives e.g., (DNT, 2012; Johnson et al., 2020; Studeregger, 2016). Currently, the main focus in the human factors part of avalanche education is on learning about typical errors in judgment and group dynamics. Repeating errors have been identified by analysing avalanche accident reports and are referred to as heuristic traps, cognitive shortcuts used in decision-making that lead to accidents (I. McCammon, 2004, 2009). The term *trap* is in line with Tversky and

Kahneman's heuristics-and-bias work, who argued that the use of frameworks reducing cognitive effort could lead to negative outcomes (Tversky & Kahneman, 1972). However, in many real-world situations, heuristics support decision-makers in arriving at satisficing solutions, the focus of the fast-and-frugal-heuristics approach. From this perspective, the heuristics-and-bias approach's main problem is that it compares people's decisions and the predictions of "rational" decisions defined by logic or statistical models (Gigerenzer & Gaissmaier, 2011). Instead, when studying how people ideally should make decisions, one should consider how people are *able* to make decisions. A wide range of studies has researched fast and frugal heuristics from this perspective (Gigerenzer & Gaissmaier, 2011; Hertwig et al., 2019). This research has identified fast and frugal heuristics that lead to a judgment that equals or even outperforms judgment based on careful analysis. An example is a study on emergency medicine. A fast-and-frugal decision tree asking yes and no questions proved to be more accurate in predicting actual heart attacks than the considerably more complex alternative based on logistic regression (Gigerenzer & Gaissmaier, 2011). Some avalanche researchers acknowledge the limitations of the heuristics-and-bias approach, and in a recent article on heuristic traps and avalanche education, the authors point out that the human factor's role in avalanche decision-making is far too complex to be understood solely within the heuristic trap framework (Johnson et al., 2020).

1.3.11 Decision makers

In this thesis, different terms are used when referring to those who make decisions in avalanche terrain. Thus, there is a need to clarify what is meant by the various terms.

- Backcountry skiers: people that ski or snowboard in uncontrolled terrain in the backcountry, regardless of competence level.
- Backcountry recreationalists or recreationalists: People that recreate in the backcountry. The term includes activities such as skiing, snowboarding, snowmobiling, ice-climbing, and snowshoeing. The level of competence regarding avalanche decision-making can vary from novice to expert. Thus, when using this term, it is not the intention to underestimate this group's competence but separate them from those we refer to as experts.
- Expert/professional: A person that has a large share of his/her daily work in avalanche-prone terrain, performing real-life decision-making on behalf of themselves

and in some cases others, and has done this for many winter seasons. An expert can typically be a mountain guide, avalanche forecaster, or professional free skier.

1.3.12 Avalanche education

In this section, I give a brief overview of educational formats available to backcountry recreationalists. When education is seen in the context of the decision-making environment, risk and uncertainty, human factors, available methods, and the other background concepts presented, the challenges, opportunities, and limitations of current avalanche education become easier to grasp.

Avalanche courses

The organization of avalanche education varies from country to country. In both the US and Canada, avalanche education seems to be reasonably standardized, probably due to the strong position of national avalanche organizations that are also educational institutions (AIARE, 2021; CAA, 2021). In Europe, avalanche education varies between each country and, in some cases, also within a country. The main course providers are mountaineering schools, Alpine clubs, and other outdoor organizations. In most cases, education is linked to the preferred decision-making framework of the course provider. In Austria, for example, this means that two different methods, which have very different approaches to decision making, are taught. The Austrian Alpine club (ÖAV) teaches the Stop or Go method (probabilistic) (Larcher, 1999), whereas Naturfreunde teaches the W3 method (analytical) (Studeregger, 2016). A similar situation is found in Norway. Two different decision-making frameworks, the Afterski method (probabilistic) (Brattlien, 2014) and Skikompis (analytical) (Lundberg, 2018), are presented in books written in Norwegian. Because most Norwegians read English well, other methods, such as Avaluator (P. Haegeli, 2010) are available to the Norwegian public and have some prevalence. While some schools that offer outdoor training have taught the Afterski method, the country's largest avalanche course provider, The Norwegian Trekking Association (DNT), and members of the umbrella organization Norsk Fjellsportforum (NF) use the approach described in Skikompis.

In Switzerland, the situation is different. The Swiss core training team of Snow Sport Avalanche Accident Prevention (KAT), a national umbrella organisation for avalanche education stakeholders, has agreed on and published the leaflet "Caution - Avalanches! " (S. Harvey, Rhyner, Dürr, Schweizer, et al., 2018) that serves as the basis for avalanche

education. There would probably be a lot to gain from standardizing and harmonizing avalanche assessments nationally like in Switzerland, and internationally too. An exciting idea would be if experts from different countries came together to develop best practices. The initiatives by *mountainsafety.info* on avalanche rescue and mountain emergency medicine shows that this can be done. An obvious advantage would be the financial savings of developing and maintaining only one set of teaching concepts, curriculums, and teaching materials. Another advantage is that skiers who got their training from different providers or countries would use the same method when skiing together. Differences aside, most avalanche courses focus on teaching many of the same basic skills such as trip planning and the use of an avalanche forecast, understanding basic avalanche formation, recognize avalanche terrain, route finding, safe travel behaviour, and companion rescue. The courses' duration is from a few hours to several weeks, depending on the target group and how much time the participant is willing to invest in learning the skills. The most common courses for recreationalist are weekend courses. Many recreationalists realize that a basic avalanche course is not enough and attend other courses on a higher level after gaining some experience.

Avalanche safety literature

Another source of knowledge and learning are books. There is a rich selection of avalanche books in different languages. The books vary in scope and how thoroughly each topic is treated, depending on the audience they address e.g., (D. McClung & Schaerer, 2006; O'bannon, 2012; Tremper, 2001). While some of the books primarily convey avalanche knowledge, some also include presentations of specific decision-making frameworks e.g., (Brattlien, 2014; Engler, 2001; S. Harvey et al., 2012; Munter, 1997). Interestingly, even though the books present decision-making frameworks that differ in overall approach (probabilistic or analytical), they present more or less the same avalanche fundamentals. It is also interesting to note that human factors have gained significantly more attention in books published in recent years.

Internet

Books are not the only source of information and knowledge. Many backcountry recreationalists educate themselves using various sources on the internet. There is a rich selection of both articles and videos that explain anything from search and rescue to near-surface faceting. Also, one should also not underestimate the learning effect of reading the

avalanche forecast and its supplementary material. Another knowledge source is avalanche-specific podcasts, such as the Norwegian *Skredpodden* or the English-speaking *The avalanche Hour*. During the corona pandemic, the number of online avalanche seminars has increased dramatically and become very popular. In addition, there are various online avalanche forums where one can ask questions and discuss various topics. For many, it is more natural to seek knowledge on the internet than to immerse themselves in a book.

E-learning

The latest addition to the strain of avalanche teaching methods is e-learning. Even though e-learning has been around for a few years, it is still in the experimental and developmental stage. Technological development has been rapid, and probably the possibilities in that type of learning will develop further in the coming years. The most elaborate and comprehensive online tool currently is *Whiterisk*, developed at the WSL Swiss Institute for Snow and Avalanche Research SLF. Other less-comprehensive solutions also exist, such as *Avysavvy* by Avalanche Canada and the KBYG (Know Before You Go) avalanche awareness program developed by Utah Avalanche Center. The potential of this form of learning in avalanches has not been sufficiently investigated. However, studies from other disciplines suggest that a combination of traditional field-based training and e-learning is beneficial. Indeed, several studies show that hazard perception skills improve significantly using both field-based and video-based training methods (Kuiken & Twisk, 2001). Computer-based scenario training would allow the students to learn to recognize and assess critical cues and repeatedly test their abilities without risk exposure. Students also benefit from this type of learning by improving knowledge retention (Helsdingen, van Gog, & van Merriënboer, 2011; Karpicke & Roediger, 2008). There are some apparent advantages of computer-based training. Nevertheless, it cannot replace practical field-based training. It can potentially serve as a supplement that complements and compensates for some of the outdoor teaching challenges.

1.3.13 Framing of a message

Framing is a cognitive bias that could be exploited for avalanche safety, like asking “why is it safe?” instead of “why is it dangerous?”. Framing implies how a situation, event, object, or problem is described, affects how people respond to or evaluate it. For example, an experiment showed that the verb *smashed* resulted in a higher speed estimate than the verb *hit* by participants who were asked to give a speed estimate based on a film of a car accident

(Loftus & Palmer, 1974). The effects of framing are diverse and of interest in many disciplines from psychology, economics, political science, and health sciences both from a theoretical and applied perspective (Chong & Druckman, 2007; Kuhberger, 1998; Levin, Schneider, & Gaeth, 1998; Maule & Villejoubert, 2007). Especially relevant for avalanche research are the accounts of framing that highlight attentional processes. These state that a frame prompts the cognitive system to direct attentional resources toward a certain perspective on the target(s) of judgment while suppressing attention toward alternative perspectives (Keren, 2011; Teigen, 2015). For example, when the avalanche forecast predicts that the chances for a heavy snowfall are "greater than 60%" it guides attention toward the occurrence, whereas a forecast of "less than 60%" guides attention toward the non-occurrence of a heavy snowfall. In avalanche warning and when performing an avalanche assessment, the term danger is often combined with the terms avalanche, conditions, or terrain. One possible reason for this is that it is easier to say that something has some degree of danger than to say that something is safe with certainty. The choice of frame may also be influenced by liability or ethical issues. In the case of an accident, it may be perceived as more likely to be sued if safe is used rather than dangerous. A person may also be more likely to blame her/himself if safe was communicated instead of dangerous. Nevertheless, the use of the term *danger* will direct the decision maker's attention during the judgment process and potentially affect his or her decision-making.

2 Objectives and structure

2.1 Goal and approach

The overall goal of my research is to contribute to avalanche accident prevention. More precisely, this thesis aims to gather more insight into the foundation in avalanche decision-making, with the intention of improving decision quality. This must not be confused with "better" decisions or decision outcomes. In an uncertain environment, the best decision does not necessarily lead to a wanted result. Improving decision quality is about increasing our chances of good outcomes, not guaranteeing them.

Initially, the ambition was to develop and test a new decision model with the working title "Why is it safe - enough?" (WISE). However, it quickly became clear that the first step had to be a study of the current decision basis for avalanche terrain decision-making. Understanding the overall approaches (analytical or probabilistic) of existing DMFs and having in-depth knowledge of all the "puzzle pieces" that form the basis for avalanche

decisions is crucial. This forms the background for another field of research and development - the improvement of decision quality based on psychological and pedagogical know-how.

The study of decision-making in avalanche can be divided into the studies of decision basis, studies of the decision process (psychological aspects) and studies on decision competence. The main focus of this thesis is on the decision basis. However, aspects of decision competence and decision process are also studied.

Table 1 Improving decision quality depends on decision basis, decision competence and the decision process. The main focus of this thesis is on decision basis. The elements in bold text are adressed in the different studies. ¹⁾ The study on risk attitude and perception is mentioned, but not included in this thesis.

DECISION-MAKING IN AVALANCHE TERRAIN				
DECISION QUALITY				
DECISION BASIS			DECISION COMPETENCE	DECISION PROCESS
DECISION-MAKING PHASES			DEVELOPING COMPETENCE	PSYCHOLOGICAL ASPECTS
TRIP PLANNING <i>Where to go when, with whom</i>	ROUTE SELECTION <i>Information update and alternative routes</i>	SLOPE SPECIFIC <i>Deciding what terrain (which slope) to ski or not</i>		
-Avalanche forecast -Weather forecast -Available areas -Available routes -Group composition	-Verification of forecast -Information sampling -Actual avalanche problems -Snowpack evaluation and tests -Actual weather -Previous traffic -Alternative routes	-Information sampling -Actual avalanche problems -Snowpack evaluation and tests -Actual traffic -Group management -Risk reduction	-Education -Experience -Pedagogy -Exposure -Reflection -Calibration of ability	-Framing -Heuristics -Motivation -Feelings -Group dynamics -Strategy -Risk attitude and perception ¹⁾
Paper I, II and IV	Paper I and II		Paper III	Paper V

2.2 Research questions

This thesis addresses the following overarching research question: *What is the basis for decisions in avalanche terrain?* This is split into five broad research questions with sub-questions that guide the different studies:

1. *What is the decision-basis of existing decision-making frameworks?* This research question is addressed in chapter 4.
 - a. What are the underlying factors in existing decision-making frameworks?
 - b. Which of these factors are shared amongst several frameworks?
 - c. Which of these factors, and any others are used by experts?
2. *Do experts use existing decision-making frameworks? and which, if any, of the factors in these frameworks do they employ?* This research question is addressed in chapter 5.
 - a. Are avalanche experts familiar with the most commonly used frameworks in Europe and North America?
 - b. To what extent do experts use these frameworks in their decision-making in avalanche terrain?
 - c. Do avalanche experts evaluate the same factors as the ones used in the frameworks, and how important are these factors in different stages of an outing?
 - d. Which factors are most commonly used by experts, independent of their background? And are these factors regarded as decisive, relevant, or irrelevant in the different phases of an outing?
 - e. Do the factors used differ between those that have experienced avalanche accidents or incidents where they or someone in their group was caught by an avalanche and those without any experience of avalanche accidents?
3. *Does avalanche education affect the assessment and judgement of avalanche risk factors?* This research question is addressed in chapter 6.
 - a. Do backcountry recreationalist believe the risk of avalanches can be assessed given enough information and knowledge?

- b. Do recreationalist and experts agree which factors are relevant?
 - c. How will recreationalists rate how precisely a factor can be assessed?
 - d. Does avalanche education and experience influence the ratings?
4. *How do backcountry recreationalists use and understand different avalanche forecast elements?* This research question is addressed in chapter 7.
- a. Which risk factors are considered as most difficult to assess and manage?
 - b. Which elements in the warning are considered as most and least important?
 - c. Which elements are easily misunderstood or considered poorly communicated?
 - d. What kind of information and features are missing or ignored by users?
5. *Does the qualitative frame in the question eliciting the risk judgment influence the judged safety of scenarios of backcountry skiing in avalanche terrain?* This research question is addressed in chapter 8.

2.3 Structure of the thesis

This dissertation consists of five individual studies contributing with increased knowledge on the foundation in avalanche decision-making. Several studies build on findings from the other studies, which increases the overall significance of the studies. However, each study asks and answers its own research question and is important independently of the others. It has been important to make the individual studies available to the relevant groups in various ways. Therefore, table 2 contains conference proceedings and popular science articles in addition to the papers submitted to or published in peer reviewed journals.

Table 2. The table presents an overview of research questions, structure of the thesis, and associated papers. Additional conference proceedings and popular science articles are indicated with the letters a-d.

Research question	Structure of the thesis	Publications, Conference Proceedings, Manuscripts, Popular Science Articles
What is the decision-basis of existing decision-making frameworks?	Underlying factors in 10 most common used DMFs	Paper I: Landrø, M., Pfuhl, G., Engeset, R., Jackson, M., & Hetland, A. (2020). Avalanche decision-making frameworks: Classification and description of underlying factors. <i>Cold Regions Science and Technology</i> , 169, 102903. doi:10.1016/j.coldregions.2019.102903
Do experts use existing decision-making frameworks? and which, if any, of the factors in these frameworks do they employ?	Usage of these factors by experts	Paper II: Landrø, M., Hetland, A., Engeset, R., & Pfuhl, G. (2020). Avalanche decision-making frameworks: Factors and methods used by experts. <i>Cold Regions Science and Technology</i> , 170, 102897. doi:10.1016/j.coldregions.2019.102897 a) Landrø, M., & Pfuhl, G. (2018). Analysis of decision-making frameworks for avalanche terrain. Paper presented at the International Snow Science Workshop, Innsbruck, Austria. b) Landrø, M., & Pfuhl, G. (2018). Wie entscheiden Experten im Lawinengelände? <i>Bergundsteigen</i> , 105, 75-80.
Does avalanche education affect the assessment and judgement of avalanche risk factors?	Ability to assess these factors	Paper III: Landrø, M., Engeset, R., & Pfuhl, G. (2020). The role of avalanche education in assessing and judging avalanche risk factors. Submitted to the <i>Journal of Arts and Sport Education</i>
How do backcountry recreationalists use and understand different avalanche forecast elements?	Understanding of forecast elements	Paper IV: Engeset, R. V., Pfuhl, G., Landrø, M., Mannberg, A., & Hetland, A. (2018). Communicating public avalanche warnings – what works? <i>Natural Hazards and Earth System Sciences</i> , 18(9), 2537-2559. doi:10.5194/nhess-18-2537-2018 c) Engeset, R., Pfuhl, G., Landrø, M., Mannberg, A., & Hetland, A. (2018). Efficacy in communication of avalanche warnings. Paper presented at the International Snow Science Workshop, Innsbruck, Austria.
Does the qualitative frame in the question eliciting the risk judgment influence the judged safety of scenarios of backcountry skiing in avalanche terrain?	Influence of frame selection on risk perception and actions	Paper V: Stephensen, M., Schulze, C., Landrø, M., Hendriks, J. & Hetland, A. (2020). Should I Judge Safety or Danger? Perceived Risk Depends on the Question Frame. <i>Journal of Experimental Psychology: Applied</i> doi:10.1037/xap0000354 d) Stephensen, M., Landrø, M., & Hendriks, J. (2021) Should We Judge Danger or Safety in Avalanche Terrain? <i>The Avalanche Journal</i>

In addition to these papers, I contributed to a study on individual characteristics on hypothetical terrain choices in my dissertation's early phase. The study resulted in one conference paper (ISSW) (Mannberg, Hendriks, Landrø, & Stefan, 2018a), one article published in the *Journal of Environmental Psychology* (Mannberg, Hendriks, Landrø, & Ahrland, 2018) and a popular science article in the mountain sports magazine *Bergundsteigen* (Mannberg, Hendriks, Landrø, & Stefan, 2018b). My contribution was mainly on

conceptualization, scenario preparation, in addition to reviewing the three manuscripts. Thematically the peer-reviewed article from this study belongs to the theme of avalanche decision-making. However, it focuses on different aspects of avalanche decision-making than what is the primary focus of this thesis. Therefore, I have chosen not to include it.

3 Methods and data

Research within the fields of avalanche prevention, avalanche safety, and avalanche decision-making frequently uses a quantitative approach, like surveys (Furman, Shooter, & Tarlen, 2012; Hallandvik, Andresen, & Aadland, 2017; Sole, 2008), accident data analysis (I. McCammon, 2004; Ian McCammon & Hägeli, 2007; Techel et al., 2015; Winkler et al., 2016) or discrete choice experiments (Furman, Shooter, & Schumann, 2010; P. Haegeli et al., 2009; Mannberg et al., 2020; Mannberg, Hendrikx, Landrø, & Ahrlund, 2018). Accident data analysis as discussed later, is a post-hoc analysis allowing some inference about when, where and who had an accident but not about the decision process itself. Discrete choice experiments, on the other hand, may lack ecological validity as they are done in the laboratory. Like other environments (e.g., traffic safety), avalanche terrain presents practical, ethical, and theoretical challenges to implementing field studies (Crandall, Klein, & Hoffman, 2006; L. Maguire & Percival, 2018).

Surveys also have shortcomings, but are an affordable, effective method of reaching out to too many people. Social media, blogs, podcasts, and backcountry related websites have proven useful in distributing surveys to relevant groups. Those who participate in these surveys must be familiar with the activity being studied. Thus, one cannot use e.g., a random selection of undergraduate students nor a paid sample recruited via Amazon Mechanical Turk or a similar platform. Although some participants may be inexperienced from an avalanche expert's perspective, they are "insiders" who have some relevant backcountry experience. However, a criticism of using surveys is that it primarily attracts very engaged participants, resulting in a skewed selection (P. Haegeli, Strong-Cvetich, & Haider, 2012). To a certain extent, this can be counteracted by targeting different user groups directly, such as participants of entry-level avalanche courses.

Field campaigns like interviewing skiers in the backcountry, avoid some of the problems of bias in surveys and have been used in several studies, e.g., (Mersch et al., 2007; Nichols, Hawley, Smith, Wheeler, & McIntosh, 2018; Procter et al., 2014; Silvertown, McIntosh, & Kim, 2007, 2009). Nevertheless, there is still a danger of getting a somewhat skewed selection because different trips appeal to different groups of skiers. Some mountains have characteristics that make them popular and frequently visited by many people, while at the same time becoming less attractive to others. The least laborious will be to seek out popular trips to get as many respondents as possible, thereby missing out on those who seek another

kind of terrain. The challenge is balancing the need to get enough data to run statistical analyses against the need to gather a representative sample.

Avalanche accidents are mainly studied using quantitative methods. Accident data can serve as a useful source of information to understand *where* and *when* accidents occur, *who* is involved, and the *causes* of an accident. Based on accident data, annual and multi-year statistics reveal patterns and trends that can be used in avalanche prevention (Mair & Nairz, 2010; Techel, Jarry, et al., 2016; Techel & Winkler, 2015; Winkler et al., 2016). Also, repeating decision errors can be identified by analysing avalanche accident reports. These errors are referred to as heuristic traps, cognitive shortcuts used in decision-making that lead to accidents (I. McCammon, 2004, 2009). Although accident data can be very useful, there are inherent biases in the data, including base rate fallacy/neglect (unknown overall population frequencies), sampling bias (only reported accidents), analysis bias (variables change over time), and hindsight bias (available information) (Johnson et al., 2020). One problem is that these biases are neglected in risk calculations, when designing DMFs (except QRM/skitouren.guru.ch), and in avalanche risk communication. Recently, attempts have been made to understand travel behaviour and actual terrain usage better (Saly, Hendrikx, Birkeland, Challender, & Johnson, 2020; Sterchi, Haegeli, & Mair, 2019; Sykes, Hendrikx, Johnson, & Birkeland, 2020). As important as these efforts are, the problems of accident data bias persist in the foreseeable future.

An alternative to the quantitative approach of surveys and avalanche accident data in studying avalanche decision-making would be the qualitative approach of interviews and focus groups. An interview is well suited to bring out the meaning of people's experiences and reveal their experiences and knowledge (Kvale & Brinkmann, 2017). The method is widely used in other disciplines, but not so common within avalanche research. However, there are some examples. In her study of expert decision-making, Adams used interviews and focus groups (Adams, 2005b), and McCammon and colleagues used a mixed-method approach, including focus groups and interviews, when studying out-of-bounds avalanche awareness (I. McCammon, Haegeli, & Gunn, 2008). Similarly, Zweifel used a mixed-method design, with online survey, intercept surveys, social network data and group interviews in his study of group decision-making (Zweifel, 2015). Another interesting study closely related to avalanche decision-making is Laura Maguire and Jesse Percival's study on the cognitive work of avalanche forecasting (L. Maguire & Percival, 2018). They used mixed-methods, including

semi-structured interviews and artifact analysis; the tools - both technological and analogue, used for avalanche forecasting.

In the following sections, I discuss the applied methods of the five studies in this thesis. A complementary explanation of each study's methodology is to be found in the publications (chapter 4-8).

3.1 Methodological design

The purpose of my thesis is to study the basis for decision-making in avalanche terrain. This led to five broad research questions and five individual studies (See table 2 for an overview of research questions and articles). Each study required independent considerations regarding sampling and methods. All but Study I, use a quantitative approach. Please see table 3 for an overview of each study's content, methods, and publications.

The use of decision-making frameworks is described in books and taught in avalanche courses. The purpose of the frameworks are to structure and help the user make decisions in the different phases of an outing. By reviewing literature that presents different DMFs, Study I classifies and describes the factors that form the basis of decisions made with these frameworks. Additional factors proposed by an expert panel were included in the study. A network analysis of factors used in each DMF displays the relationship between the frameworks.

The survey used in Study II addresses the experts, those with the most exposure to avalanche terrain. The study aimed to map the experts' knowledge and use of existing decision-making frameworks and examine their use and opinion on factors used in these frameworks.

Knowledge enables people to prioritize which information to seek, which cues to assess or monitor, and when to decide. Being able to recognize and assess different cues or factors is crucial, as is having insight into the limitations of this knowledge. Critics might argue that the assessment of factors beyond the most apparent, such as signs of instability and inclination, requires training to an extent unrealistic for most people. In Study III, a survey was used to test the understanding of avalanche risk factors among recreationalists with varying avalanche education and competence.

Avalanche forecasts are a common starting point for trip planning and thus part of the decision basis in avalanche decision-making. Study IV is twofold. An online survey targeted at avalanche professionals was used to establish an avalanche forecast's intended comprehension. The subsequent online study examined the use and understanding of different forecast elements among recreationalists with varying competence levels, as compared to the intended comprehension.

The words we use affect our perception of a situation and thus how we make decisions. Study V studies the influence of frame selection on risk perception and how it affects actions. Using a series of hypothetical scenarios of skiing in avalanche terrain, backcountry skiers judged how safe or dangerous each scenario was and indicated whether they would ski the scenario.

Table 3: Overview of the five studies with content, methods, and publications

	Content	Method	Paper
Study I Chapter 4	1) Classification and description of avalanche decision-making factors 2) Additional factors used proposed by expert panel 3) Relationship between the different DMFs	1) Qualitative: Review of existing decision-making frameworks, and review of factor-specific literature 2) Quantitative: Expert panel survey 3) Quantitative: Network analysis	Landrø, M, Pfuhl, G., Engeset, Jackson, & Hetland, 2020
Study II Chapter 5	1) Expert knowledge and use of existing decision-making frameworks 2) Expert use and opinion on factors used in decision-making frameworks	1, 2) Quantitative: Online survey - experts	Landrø, Hetland, Engeset, & Pfuhl, 2020
Study III Chapter 6	1) The role of avalanche education in assessing avalanche risk factors	1) Quantitative: Live demo and survey on mobile phone - recreationalists 1) Quantitative: Online survey – recreationalists 1) Quantitative: Online survey - experts	Landrø, Engeset & Pfuhl, 2021

Study IV	1) Establish the intended comprehension of the avalanche warning	1) Quantitative: Online survey - expert panel	R. Engeset, G. Pfuhl, M. Landrø, A. Mannberg, & A. Hetland, 2018
Chapter 7	2) The use and understanding of different avalanche forecast elements	2) Quantitative: Online survey– recreationalists	
Study V	1) The effect of choice of frame on perceived risk and behaviour decisions	1) Quantitative: Live demo and survey on mobile phone – recreationalists	Stephensen, Schulze, Landrø, Hendrikx & Hetland, A. 2020
Chapter 8		1) Quantitative: Online survey – recreationalists	

3.2 Data sets and analysis

3.2.1 Data for study I

Different DMFs have been developed to aid the decision-making process. When used, these DMFs constitute the decision basis for avalanche decision-making. Study I focus on ten widely used DMFs. These are; 3×3 and the Reduction method (Munter, 1997), Stop or go (Larcher, 1999), Snow-card (Engler, 2001), Graphic reduction method (S. Harvey et al., 2012), Afterski method (Brattlien, 2014), NivoTest (Bolognesi, 2000), ALPTRUTH (I. McCammon, 2006), Avaluator 2.0 (P. Haegeli, 2010), and Systematic snowcover diagnosis (G. Kronthaler, 2003). Other DMFs or newer versions of the included ones may exist. However, we have sought to use the latest versions and include the most used frameworks. One method that could have been relevant, but which was omitted, is the Quantitative Reduktionsmethode (QRM) (Schmudlach, Winkler, & Köhler, 2018) used in the trip planning portal skitouren guru.ch. The QRM was omitted because it differs conceptually from traditional DMFs. The main reason is that it is a trip planning tool and not a DMF that implements decision-making in different phases (trip planning, route selection, slope specific).

Previous studies have focused on calculating the prevention values of various DMFs (I. McCammon, Haegeli, P., 2004; Uttl et al., 2009; Uttl, McDouall, & Mitchell, 2012; Uttl, McDouall, Mitchell, & White, 2012), without going into more detail on the factors that constitute the basis for the decision, uncertainty associated with measuring or assessing these factors, nor the reasons for choosing the overall approach (analytical, probabilistic).

The frameworks included in Study I are often presented using a plastic-coated card or checklist that can be taken on a trip. The factors printed on these cards constitute the basis for making the decision. We refer to these as *direct* factors (e.g., the regional danger level and inclination in the DMFs derived from the RM). Most DMFs have some accompanying literature. This can be books or leaflets where the DMF is explained, and factors beyond the direct factors are presented. We use the term *indirect* factor when referring to these since they can be regarded as part of a framework but do not belong to the direct factors on the cards or checklists. We collected the factors included in the checklists, cards, or as described in the accompanying literature belonging to the different frameworks. This resulted in 44 different factors. Two of these factors stem from the avalanche forecast. An additional five elements from the avalanche forecasts were included. Next, we included one factor describing the most used stability tests, because in our experience, their use is quite common amongst experts, and they are featured in the literature accompanying some of the DMFs. We then conducted a pre-test on a panel of 10 avalanche experts of different nationalities and professional backgrounds. Based on the feedback from the pre-test, we added three additional factors. This resulted in 53 factors that are grouped thematically into five categories. Each of the identified factors was described and problematized in the light of literature relevant for each factor, such as books on snow science and snow science articles. The literature review unveiled each DMF's structure and the ideas behind the overall approach to the decision-making process. To explore the relationship between the DMFs based on the factors they use, we conducted a network analysis. By assigning binary coding as 0=not included and 1=factor included. When a factor can be regarded as part of a framework because it is included in accompanying literature or is used indirectly, we coded it as 0.5 instead of 1.

3.2.2 Data for study II

The mapping and classification of the 53 factors formed the basis for the online survey used in Study II. The study aimed to (1) gauge experts' knowledge and use of existing DMFs and (2) expert use and opinion on factors used in decision-making frameworks. This resulted in a very complex survey studying 10 frameworks, 53 factors in 3 phases. The survey used logic to customize the survey, asking only questions regarding methods and factors that were relevant to each participant. This helped limit the time it took to respond to the survey. Questions about a factor followed the same procedure. Firstly, we asked if a factor is part of the respondent's decision-making in avalanche terrain. If yes, we asked in which phase (planning, route, slope decision) the factor is used and how they evaluated the factor's

importance. To reduce a possible priming effect, we asked the experts about the use and importance of all the factors in a randomized manner, before asking questions on knowledge and actual use of existing DMFs. The survey was pre-tested on 10 participants. Based on their feedback, we improved the clarity of questions, workflow, and translations. The survey was made available in Norwegian, English, and German, providing the avalanche terminology in native language. To ensure a thorough evaluation of the different methods and factors, we purposefully recruited different expert groups in several countries who differ in their traditions and approaches regarding decision-making in avalanche terrain. The participants were recruited among experts associated with the European Avalanche Warning Services (EAWS) or among professional mountain guides (IFMGA), ski guides, mountain guide instructors, and avalanche educators from Europe and North America. Through personal friendship, we recruited some professional free skiers. We also snowballed from established contacts. All but the Canadian respondents, who were invited and encouraged by the Association of Canadian Mountain Guides, received a personal invitation to participate. We only invited persons who were thought to be on the highest level, the expert stage, according to the five-stage phenomenological model of skill acquisition (Dreyfus and Dreyfus, 2005). 121 participants visited the survey. Of those, 100 completed over 90% of the survey. Of those 100 participants, ten were female and 89 men. The sample was equally divided between respondents from Scandinavia (n=32), the German-speaking part of the Alps (n=32), and North America (n=35). On average, the respondents had 28.2 years of experience in backcountry skiing, ranging from 8 to 52 years, spent 50 days backcountry skiing per season, of which 73% were in avalanche terrain.

3.2.3 Data for study III

In study III we tested the understanding of avalanche risk factors among backcountry recreationalists. Ideally, risk assessments should be based on relevant factors that can be precisely assessed. If a factor is misjudged, the entire risk assessment might be distorted. We



Figure 2 Participants the avalanche seminar at Chateau Neuf in November 2018, Oslo, Norway Photo:Friflyt

had two groups of participants in our study. Group one included attendees at three avalanche seminars organized in a collaboration between the NAWS and the Center for Avalanche Research and Education (CARE). In the first seminar, eight factors were tested, and

237 people completed the survey. In the second and third seminars, eleven factors were tested, and 352 completed the survey. The second group was recruited from the CARE-research panel, and 630 participants answered an online version of the eleven-factor survey. The results from the two groups of recreationalists were compared with the data on expert use and opinion on factors used in decision-making frameworks from Study II. The survey consisted of questions regarding a selection of factors identified in Study I. For each factor, we asked how precise the respondent thinks she or he can assess the factor and how important the factor is for a person's avalanche risk assessment. The answer options for precision were: 1 = not very precisely, 2 = fairly precisely, 3 = very precisely. The answer options for relevance were: 1 = insignificant, 2 = relevant, 3 = decisive. I don't know this factor was also possible to choose. Participants answered either the question about precision first and the relevance question secondly, or vice versa. We asked four questions measuring aleatory or epistemic uncertainty, e.g., whether avalanches are regarded as a random event or become predictable with more knowledge, respectively (Ulkumen et al., 2016). Finally, we asked about 1) their level of avalanche training (range: 0 = no avalanche training to 6 = expert level training); 2) skiing skills and exposure to backcountry skiing (range: 0 = beginner to 6 = expert skills); 3) avalanche accident involvement (answer options: "no avalanche accident experience" to "someone I was traveling with died"); and 4) demographic questions, i.e., age, gender, years of backcountry skiing, and the average number of backcountry trips during the last three seasons.

Following two introductory lectures on avalanche safety, the online study link for participants (Qualtric software) to access via their internet-connected mobile devices was projected on an auditorium screen. Each of the factors was visually displayed on the auditorium screen while conducting the survey.

The online survey was launched on 21st February 2020 and remained open until 6th March 2020. Participants were members of the CARE-research panel and were contacted via email, explaining the background, intention, and format of the survey.

Study III included 11 of 53 decision-making factors identified in Study II. The 11 factors were selected purposely and varied in use in DMFs, importance, and uncertainty associated with assessing the factor and overall factor category. Thus, the factors set different requirements for the competence of the user. Most likely, there are some differences in self-reported and actual in-field use and understanding of a factor. To clarify this, we would have

to perform tests outdoors. It would have been difficult or impossible to test an equivalent number of participants outdoors, and thus we would have missed the variation in educational background and experience, which was the main point of the study. For details on data preparation and analysis see original paper.

3.2.4 Data for study IV

Previous studies suggest that avalanche forecasts are used extensively in trip planning and have a relatively strong influence on people's decisions (Furman et al., 2010; Hallandvik et al., 2017; Marengo, Monaci, & Miceli, 2017). Still, no evaluation concerning how efficiently the content is communicated and understood has been done to date. To manage avalanche risk successfully, it is fundamental that the content is understood and translated into practice by a wide range of different user groups. Along with any local knowledge, information from maps, guidebooks, weather forecasts, and the group's composition, the avalanche forecast forms part of the basis for avalanche decision-making.

The data in this study comes from two online surveys conducted during the autumn of 2017. The purpose of the expert survey was to establish an avalanche forecasts intended comprehension. We wanted to identify key information elements and define sets of behavioural implications at different avalanche danger scenarios. To ensure that the operationalization was valid, we used a relatively large (n=110) and heterogeneous group of avalanche experts (mainly professional avalanche observers and forecasters). Each expert was randomly exposed to one out of four alternative ways to present the forecast for each danger level. We then asked the experts to rate how well the danger was communicated in the example, on a scale from 0 to 10. Next, the experts were asked to identify key information elements and behavioural implications of the avalanche forecast. We were specifically interested in identifying the most important message that the forecast aimed to communicate. The expert answers were used to allocate weights to the different behavioural implications and establish a communication effectiveness score.

The second survey intended to test how well non-expert users understood the NAWS message and therefore targeted recreational users of the NAWS. Participants were recruited via social media, NAWS web page - varsom.no, and different web pages addressing backcountry recreationalists. In addition, the Norwegian Hiking Association (DNT) and the Norwegian association of snow scooter clubs (Skuterklubbene's fellestråd) distributed the survey to their members. The survey was distributed to different backcountry recreationalist "scenes", ranging from free riders, backcountry skiers, snowshoers, and snowmobilers. This

was done to counteract the survey being answered by one particular group of interested and committed people.

A total of 485 respondents answered the user survey. Not all respondents answered questions in all sections, leaving 361 respondents to analyse avalanche warning, 222 respondents for analysis of text versus symbols and pictures, and 177 respondents to analyse comprehension. The lower number of user respondents completing the entire survey reflects a common challenge in online surveys to engage participants enough to answer complex and time-consuming questions.

The goal of the study was to investigate the use and understanding of different avalanche forecast elements. Because the forecast is part of the basis for decisions in avalanche terrain, it is fundamental that the content is understood. If the goal had been to study actual behaviour after reading an avalanche forecast, direct observation would be a valuable methodological approach.

3.2.5 Data for study V

Across six experiments (n=1599), we tested how risk perceptions and decisions are influenced by the qualitative frame of the question that elicits the risk judgment (e.g., the question frame). Using a series of hypothetical scenarios involving backcountry skiing in avalanche terrain, participants judged either how safe or how dangerous each scenario was and indicated whether they would ski the scenario. Each of the six experiments was conducted during a public seminar on safety and decision-making for backcountry skiers in avalanche terrain, with the seminar audience members as participants.

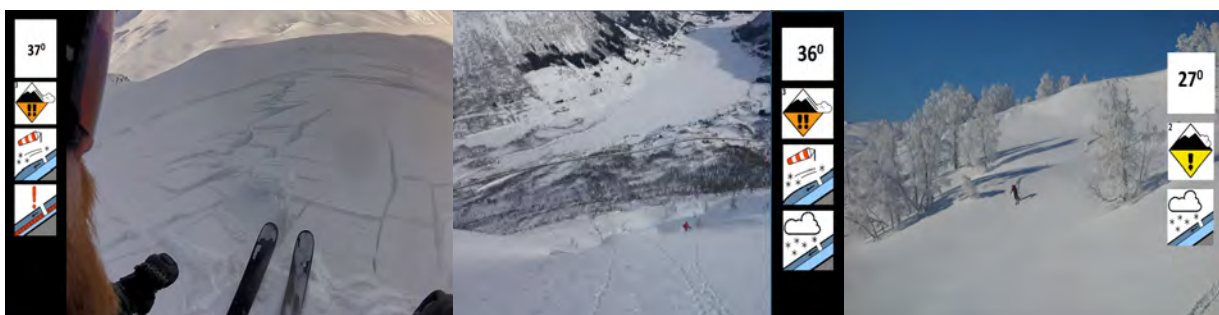


Figure 2 **Left picture:** Example of dangerous scenario. Dangerous scenarios displayed photos with definite evidence of danger, a slab avalanche in motion. The icons substantiated the information from the image. **Center picture:** Example of uncertain scenario. Uncertain scenarios lacked definitive evidence of safety or danger because the available evidence in the photo and the icons were ambiguous, conflicting and/or highly interpretable. **Right picture:** Example of safe scenario. The photograph and icons in the safe scenarios conveyed sufficient evidence to ascertain the objective safety of the scenario. Photo: K. Myking (L) and M. Landrø (C,R)

Each seminar was at a different location in Norway during the winter of 2019 to 2020. The six seminars' audience members were recreational backcountry skiers with varying degrees of experience judging avalanche risk during ski tours in avalanche terrain. Consequently, there was a self-selection for experienced participants in all six experiments. We did not conduct a priori power analysis to determine target sample size for any experiment. The audience size at a seminar determined the possible number of participants in the study conducted at that event. We recruited as many participants as possible during each seminar and did not continue data collection for the respective experiment beyond that seminar, but otherwise had no control over each study's final sample size. We set a minimum sample size for each experiment of approximately 60% of the anticipated audience size for that seminar. Participation exceeded 60% of the actual audience size for all six experiments, and we met the estimated minimum number of participants for experiment 1 to 5. Although more than 60% of the audience participated in experiment 6, we overestimated the expected audience size and did not meet the minimum number of expected participants. All six studies used the same experimental design, measures, and procedures. We used a between-subject design with two experimental conditions—the Safe Group or the Danger Group—for the qualitative attribute that framed the risk judgments. Following two introductory lectures on avalanche safety, the online study link for participants to access via their internet-connected mobile devices was projected on an auditorium screen. Upon accessing the study, participants were randomly assigned by the software to one of the two experimental conditions after indicating their informed consent to participate.

Participants in experiment 1 to 4 judged six uncertain scenarios. We used the same six uncertain scenarios for all four experiments, changing their order of presentation between studies to account for any possible order effect. Participants in experiment 5 and 6 judged ten scenarios: four scenarios of uncertain risk, three safe scenarios, and three dangerous scenarios. We used the same set of ten scenarios for both experiments. The four uncertain scenarios used in experiment 5 and 6 were selected from among the six uncertain scenarios previously used in experiment 1 to 4. The three safe scenarios and the three dangerous scenarios used in experiment 5 and 6 were new. We anticipated the possibility of an effect from the order in which the categories of scenarios were judged. We therefore reversed the order of presentation between experiment 5 and 6. In experiment 5, we first presented the three dangerous scenarios followed by the four uncertain scenarios, and lastly the three safe scenarios. In experiment 6, we first presented the three safe scenarios, then the four uncertain

scenarios, and finally the three dangerous scenarios. Although we reversed the order of the scenario categories in experiment 6, the order of the scenarios within each category was the same in both experiments.

The scenarios were sequentially projected onto the auditorium screen for all participants in the audience to see. All questions were displayed exclusively in Qualtrics (survey software) on participants' personal mobile devices. Participants in the Safe Group judged the scenarios by answering the question "*How safe is it?*" responding on a 7-point scale labeled "*Not at all safe*" and "*Completely safe*" at the extreme points. Participants in the Danger Group judged the same scenarios by answering the question "*How dangerous is it?*" responding on a 7-point scale labeled "*Not at all dangerous*" and "*Completely dangerous*" at the extreme points. Upon completing each risk judgment, participants in both experimental groups were asked the question "*Would you ski this slope?*" with the three response options "*No*", "*I cannot say*" or "*Yes*". Participants had approximately one minute per scenario to answer the risk judgment and the behaviour intention questions before the next scenario was projected. Participants were instructed not to discuss with their neighbours during the study and the seminar leaders confirmed that all auditoriums were silent during data collection.

For this study we developed three categories of scenarios: scenarios of uncertain risk, safe scenarios, and dangerous scenarios. I selected photographs from my personal library and assigned icons to those photographs to create scenarios of differing risk level. The combination of visual evidence in the photograph and the information conveyed by the icons established the objective risk level of each scenario.

The objective uncertainty was independently confirmed by a second avalanche expert. Ideally, we could have established a gold standard by asking a group of experts to evaluate and rate each scenario. Unfortunately, there was no time to conduct such an expert panel assessment before the avalanche seminars where the survey was conducted. The possibility of data collection opened up unexpectedly, and the scenarios had to be created relatively quickly. This could, of course, have been done afterward, but the results showed that the participants did not have problems distinguishing between safe, unsafe, and dangerous scenarios. Indeed, uncertainty was not a requirement for the framing effect. Therefore the need to involve one expert panel was not present. The dangerous and safe scenarios were deliberately made very clear and conveyed sufficient evidence to ascertain the scenario's objective safety or danger. All three dangerous scenarios displayed photos with definite

evidence of danger, a slab avalanche in motion, and the icons substantiated the information from the image. Similarly, in the safe scenarios, the stated slope inclination is low, respectively 27°, 25°, and 30°. Supplemented with cues shown in the picture (e.g., forest density, snow on trees, no runout zone), the scenarios are objectively safe because all the evidence aligns to indicate that an avalanche is extremely unlikely. In contrast, the uncertain scenarios lacked definitive evidence of safety or danger because the available evidence in the photo and the icons were ambiguous, conflicting, and/or highly interpretable. For details on data preparation and analysis see original paper.

4 Study I. Mapping and review of factors used in avalanche decision-making frameworks.

Researchers and avalanche experts have developed a range of avalanche decision-making frameworks to support decision-making in avalanche terrain and reduce fatalities. These frameworks rely on and assess different factors. We collected 44 factors included in the checklists, cards, or as described in the accompanying literature belonging to the different frameworks. Nine other factors were added based on feedback from pretesting our survey, resulting in 53 factors. Each factor is described, and the eventual uncertainty associated with measuring or assessing these factors is addressed. Our analysis shows that the factors included in the different frameworks range from simple to complex and simplifications of complex factors. Some factors are used from a statistical perspective in some frameworks, whereas others assess the same factors as a physical factor. There are differences in the number, type, and importance of factors amongst existing decision-making frameworks for avalanche terrain. The consequences of these differences are:

- Different DMFs can give conflicting results when it comes to go or no-go decisions
- Different DMFs pose different demands on user knowledge and competence
- DMFs differ in ease of use
- DMFs differ in the level of residual risk they accept
- DMFs differ in the amount of terrain regarded as accessible under the same conditions

The frameworks were developed to make informed and ultimately safe decisions but the disagreement amongst the frameworks and factors used by experts warrant reconsideration

and revisions. By mapping and reviewing the relevant factors in avalanche decision-making this study provides a foundation to improve decision quality by improving the decision basis.

4.1 Contribution of Study I to the present thesis

Decision-making frameworks rely on and assess different factors. Ultimately the use of these factors provides a go or no-go decision in avalanche terrain. The study unveiled each method's structure and the ideas behind the overall approach to the decision-making process. It also forms the basis for understanding the selection of factors the developers include in their frameworks. The network analysis explored the relationship between the DMFs based on the factors they use. This study provides the first complete overview and description of all the factors used in existing DMFs. This knowledge is a crucial prerequisite to study and improve the actual decision process, the next natural step in studying avalanche decision-making and improving decision quality. Also, the 53 factors identified in Study I formed the basis for the online survey used in Study II.

4.2 Publication and presentation of study (Study I)

At the International Snow Science Workshop in Innsbruck (ISSW) in 2018 I got the opportunity to give an oral presentation of the results from Study I and II. It was a great honour to present in front of such a large and knowledgeable audience. The conference brings together researchers and practitioners from around the world to present new knowledge and share experiences. What is special about decision-making in avalanche terrain is that it matters to all that somehow are concerned with avalanches. Whether one works with snow science, studies human factors in decision-making, or works as a ski patroller, all must somehow assess avalanche danger and make decisions either at work or in their free time. After the presentation, many people contacted me to discuss the findings, provide input, and discuss new ideas. I was also invited to publish a popular science article (Landrø & Pfuhl, 2018) in the mountain sports magazine *Bergundsteigen*, the conference co-organizer, and media partner. The article is attached in the appendix. Since 1998, Cold Regions Science and Technology has publishing selected, peer-reviewed contributions at the International Snow Science Workshop in a Special Issue. This was also the case for the conference in Innsbruck. Thus, it became natural for me to publish article I in this journal.

5 Study II. Expert evaluation of factors in avalanche decision-making

The primary target group of existing DMFs is backcountry recreationalists. Most existing frameworks work with simplifications to meet the user's assumed limited experience and knowledge. This, though, risks losing the distinction between a factor's relevance in different situations and the degree of uncertainty associated with the factor's interpretation. Furthermore, simplifications may lead users who have gained some personal experience to deviate from the frameworks' original rules and structure. This raises two interesting questions: Do the experts, the ones with the most exposure and experiences with decision-making in avalanche terrain, base their decisions on the same factors as the ones used in the frameworks? And are avalanche experts familiar with and use the frameworks?

We asked 100 experts about their familiarity and usage of the DMFs and their underlying factors. We found a large discrepancy between familiarity with and actual use of the most commonly used DMFs. Our results show that experts use more factors and emphasize other factors than most DMFs do. Indeed, the factors the experts use do not match any of the DMFs well, with the agreement ranging from 56% to 73%. In contrast to many decision-making frameworks, experts perform snowpack evaluations or stability tests and consider the avalanche problem. The experts also pay attention to group skills and safety equipment and evaluate the presence or absence of favourable terrain and terrain traps. Experts frequently use additional factors not found in the DMFs. In contrast to most frameworks that have a probabilistic approach, experts primarily use an analytical one.

5.1 Contribution of Study II to the present thesis

Study II gave an expert opinion on which factors are relevant for avalanche risk assessment in the different phases of an outing. Thus, providing an overview of factors that should be taught in connection with knowledge-based analytical avalanche education and included in future analytical DMFs. In contrast to probabilistic DMFs, this would allow the avalanche assessments of backcountry skiers to evolve and grow with their experience while still using the same framework. In turn, this will ease the competence journey from novice to expert.

5.2 Publication and presentation of Study II

As previously mentioned, the results from Study I were presented in a joint oral presentation with Study II at the ISSW 2018 in Innsbruck. The article associated with Study II was published in the Special Issue of Cold Regions Science and Technology, issued after the conference. A part of Study II concerns the use of elements from the avalanche forecast in the different phases of an outing and is of interest to forecasting services worldwide. This resulted in me being invited to give an oral presentation during the 20th General Assembly of the European Avalanche Warning Services in Oslo, Norway, in June 2019. Other presentations addressed end-user needs and decision aids and lay the foundation for fruitful discussions on avalanche decision-making. These discussions initiated an ongoing project attempting to log actual decision-making in the field.

Norway hosts a bi-annual Nordic avalanche conference, and in 2019 it was held in Voss. The conference offers a wide range of topics but especially attracts people who work with avalanche education in various ways. I was given the honour of being the keynote speaker on one of the conference days. I presented findings from Study II, because they have implications for avalanche education in general and avalanche decision-making in particular. The presentation ended with an interesting panel debate on avalanche education in Norway, where representatives from the largest educational institutions were represented. I find such discussions very useful since they contribute to an increased common understanding and consensus on avalanche education.

6 Study III. Avalanche education and the assessment of avalanche factors

The study shows that the ability to assess avalanche risk factors is dependent on and improve with education. Further, it shows that the relevance rating of avalanche risk factors amongst beginners is similar to that of experts.

6.1 Contribution of Study III to the present thesis

Whereas Study II examined expert use and opinion on factors used in existing DMFs, Study III included backcountry recreationalists on different levels of competence. The aim was to examine the role of education in the assessment of avalanche factors. A factor's relevance did not depend on avalanche education. However, education influenced how precisely the factor could be assessed. Thus, this substantiates that even non-experts could

apply analytical, knowledge-based decision-making given the proper education. This allows for the development of decision-making tools with an overall approach that has previously been reserved for experts.

6.2 Publication and presentation of study (Study III)

The paper associated with Study III is submitted to the *Journal for Research in Arts and Sports Education* special issue with the theme: Outdoor life, education, learning and didactics. As Study III studies the role of avalanche education on the assessment and judgement of avalanche risk factors, and the findings have implications for avalanche education, I believe it fits well to this journal.

Hopefully, I will have the opportunity to present the findings both from this and the other studies at the Nordic avalanche conference in autumn 2021 and at ISSW in 2022. All the articles are about improving the quality of decision-making, albeit with a slightly different focus. These conferences are an excellent opportunity to discuss decision-making quality at an overall level and the road ahead for research and education.

7 Study IV. Avalanche danger communication and understanding

In Study IV, we investigated how efficiently the NAWS forecast's content is communicated and understood amongst recreational users. We first asked a panel of experts from NAWS to answer the survey and used their answers to establish the avalanche warning's intended comprehension. We recruited over 200 recreational users and compared their answers to those of the experts for the different communication modes. Because the forecast is part of the basis for decisions in avalanche terrain, it is fundamental that the content is understood and translated into appropriate practice. We identified elements in the avalanche warnings that recreational users perceive to be of greater or lesser importance, are easily misunderstood or missing. Our empirical analyses suggest that most users find the warning service useful and well suited for their needs. However, the effectiveness of a forecast seems to be influenced by the user's competency and the complexity of the scenarios. The testing of the effectiveness of different alternatives for communication of level 2 - moderate and level 4 - high avalanche danger suggested that the avalanche problems communicated more effectively than the danger level at lower danger. At the higher danger levels, no significant difference was found between the alternatives. The results suggest that a simple danger rating

is not enough to convey the intended warning message on lower danger levels. Rather the warning should present the avalanche problem with a reasonable level of details. The results suggest that leaving out the advice and explanation resulted in lower comprehension at higher danger levels. For danger level 2 - moderate, a user's competence mattered when it came to the alternatives' rating, but not for danger level 4 - high. Most experts (79 %) and many recreational users (65 %) rated the avalanche problem as the most important warning element. The danger level was rated as important but somewhat difficult to understand. It is a simple numeric value but is determined from relatively complex and subjective factors and is probably difficult for users to understand and use. The avalanche danger level is not enough for making decisions in avalanche terrain; more detailed information is needed, especially at danger levels 2 and 3, which also are the conditions under which most fatalities occur. A relatively large share (more than a third) finds it difficult to identify terrain traps and manage others in the group, illuminating the need for basic avalanche training. Another finding that underscores the need for good and targeted avalanche education is that a considerable share of both expert and recreational respondents state that they find it most difficult to assess and manage the snow cover. This challenges avalanche warning services to present the avalanche problem, snowpack information, and danger description more systematically and pedagogically to increase the understanding and improve the users' competence. It should be noted that even the experts considered the snow cover as the most difficult factor, suggesting that it is complex to manage for users at all levels.

Based on the findings in this study, NAWS redesigned the avalanche forecast on Varsom.no: the communication of the avalanche-prone locations was improved, the display of avalanche problems was moved up to just below the main message, the redundancy in information between the avalanche problem, snowpack information, and the avalanche danger description was reduced.

7.1 Contribution of Study IV to the present thesis

Along with any local knowledge, information from maps, guidebooks, weather forecasts, and the group's composition, the avalanche forecast forms part of the basis for avalanche decision-making. To manage avalanche risk successfully, it is fundamental that the forecast content is understood and translated into practice. This study agrees with previous research and confirms the forecast's importance and role as the primary source of information in the trip-planning phase. Regardless of which DMF one chooses to use, it is beneficial to

divide the decision-making process into several phases. It serves as an increasingly fine-meshed net that allows the user to update and review the decision basis from the previous phases. Therefore, the forecast should also be integrated into new methods, as this study indicates. Furthermore, the study highlights weaknesses and opportunities for improvements in the presentation of some of the forecast elements. The study also showed the need for education to use the forecast's various elements as part of the decision basis.

7.2 Publication of study and contribution to actual changes (Study IV)

The journal *Natural Hazards and Earth System Sciences* is dedicated to research on natural hazards and their consequences. It welcomes research on strategies to reduce the impact of natural hazards on society and individuals and has previously published articles on avalanche risk management. The results are relevant to avalanche safety and warnings, but it is also relevant for communication of risk and warnings of other types of natural hazards. Thematically, Study IV fit well in this journal, so the authors chose to publish here.

As a result of the findings in study IV, the NAWS made visual changes to two essential icons used in the forecast (height level and aspect). It also led to a restructuring of the forecast's presentation and an increased emphasis on the avalanche problem. The study revealed a need for training, especially in terms of basic avalanche knowledge and vocabulary. This has led to an investment in training materials, both in writing and short films, available on the NAWS web page.

8 Study V. Perceived risk and question framing

Framing implies how a situation, event, object, or problem is described, affects how people respond to or evaluate it. The fifth study in this thesis presents results from an experiment conducted during a series of avalanche awareness seminars. Using a series of hypothetical scenarios of skiing in avalanche terrain, backcountry skiers judged how safe or dangerous each scenario was and indicated whether they would ski the scenario. This study demonstrates that risk judgments framed in terms of safety (How safe is it?) result in more cautious, conservative judgments than when framed in terms of danger (How dangerous is it?), irrespective of the objective risk of the judged object. These findings advance our understanding of the framing effect while illustrating its particular relevance for applied risk perception practices.

8.1 Contribution of Study V to the present thesis

Improving decision quality is not all about the factors included in the assessment, or the decision basis as it is referred to in this thesis. It is also about improvement of the decision process itself. Framing is a cognitive bias that could be exploited for improving decision quality by asking “why is it safe?” instead of “why is it dangerous?” during an assessment. The use of the term “safe” will direct the decision makers attention during the assessment and potentially affect his or her decision-making. When using an analytical approach in avalanche decision-making, the user should be encouraged to ask, "why is it safe?" instead of "why is it dangerous?" because it results in more cautious, conservative judgments. Further, asking questions about one's own and others' assessments, e.g., "why is it safe?" could also increase assessment transparency. The basis for the decisions becomes visible and errors, misunderstandings and shortcomings may be discovered. Clues that are overlooked by some but not by others can be included in the assessments. It also provides a vehicle for discussing the assessments themselves and the level of confidence.

8.2 Publication and presentation of study (Study V)

In Study V the judgment task was shaped by the uncertainty of avalanche terrain and this research has applied relevance specifically for the field of avalanche safety. However, the research also has relevance for a wider audience. Therefore, the study was published in the *Journal of Experimental Psychology: Applied*. This journal covers research in experimental psychology that bridge practically oriented problems and psychological theory.

Study V was presented as a poster at the Virtual Snow Science Workshop 2020. This was an alternative to the originally planned 2020 ISSW in Fernie, Canada. After the conference, the authors were invited to write an article on the framing research for the *Avalanche Journal*. This is the official publication of the Canadian Avalanche Association, that keeps its members informed about current research, training and products. This was an opportunity to reach a relevant audience that can translate this research into practical measures. The popular science article in the *Avalanche Journal* is translated, compressed, and submitted to *Viten*, which is the popular science part of a major Norwegian newspaper, *Aftenposten*.

9 Discussion

9.1 The decision basis and beyond

In avalanche decision-making research, there has been a research gap regarding the decision basis. This thesis aims to fill parts of this gap and gather more insight into the foundation in avalanche decision-making to improve decision quality. Decision quality is a result of decision basis, decision competence, and the actual decision process. The main focus of this thesis is on the decision basis. However, aspects of decision competence and decision process that have implications for the decision basis are also studied. In addition to the research gap, this thesis is motivated by my personal experience of major differences among backcountry skiers when assessing avalanche danger. Also, in my experience, existing methods are somewhat used in an educational context, but their use is not widespread beyond this. Considerable resources are spent developing the frameworks and creating educational concepts, but the dealignment between training and practice is worrying. The overarching research question in this thesis is: What is the basis for decisions in avalanche terrain? This is split into five broad research questions that guide the different studies.

I started by investigating existing decision-making frameworks. By reviewing literature describing the most commonly used DMFs, I identified each framework's underlying assessment factors. This overview is crucial to understand the structure of existing frameworks and makes it possible to compare their decision basis. I followed research question 1: *What is the decision-basis of existing decision-making frameworks?* 44 factors were identified. An expert panel provided an additional nine factors commonly used by experts, resulting in a total of 53 factors. Each factor was described, and eventual uncertainty associated with measuring and assessing the factors was addressed. This study differs from previous studies that have focused on calculating prevention values without detailing the factors that constitute the basis for the decision or problematizing the choice of an analytical or probabilistic approach. The avalanche field is constantly evolving, so are the decision-making frameworks. When the work on this dissertation started four years ago, I tried to find the latest updated versions of all the frameworks. Since then, both new versions of existing and completely new ones have been developed (Mersch & Hummel, 2020; Reuter, Semmel, Mallon, & Schweizer, 2021; Schudlach & Köhler, 2021; Semmel & Reuter, 2021; Studeregger, 2016), and the frameworks decision basis and overall approach are being discussed (Behr & Mersch, 2021). These updated versions and new initiatives are not

included in this thesis. However, my impression is that currently in Europe, greater emphasis is placed on the analytical approach, especially in the last two phases of an outing, after the probabilistic approach has long dominated avalanche decision-making. Another interesting development is that consequences are included in the assessment in some of the frameworks (S. Harvey, Rhyner, Dürr, & Henny, 2018; Reuter et al., 2021). A whole new addition to the strain of frameworks is the AIARE Risk Management Framework, which includes both education and evaluation in its different phases (AIARE, 2021). Another development that has gained momentum due to technological innovation and computing power is trip planning tools such as skitourenguru.ch, which will be discussed in section 9.3.

After mapping the frameworks and identifying their underlying factors, it was paramount to study the decision basis of experts. The second research question guided this study: *Do experts use existing decision-making frameworks? And which, if any, of the factors in these frameworks do they employ?* The study revealed a large discrepancy between familiarity with and actual use of the most commonly used DMFs. It also showed that experts use more factors and emphasize other factors than most DMFs do and primarily use knowledge-based analytical decision-making. An alternative approach to the chosen use of an online survey could be direct observation or interviews. Observing people's decision process, subsequent actions - witnessing outcomes - would pose practical, theoretical, and ethical challenges (Crandall et al., 2006; L. Maguire & Percival, 2018). Focusing on the practical and theoretical aspects, it would require some participant decision-log or in-situ interview since it is impossible to observe all the factors included in the decision process and their significance in the given situation. This, in turn, would require each participant to be observed in many different situations to cover the spectrum of different avalanche conditions. The workload to study the necessary sample would be prohibitive. An alternative would be interviews. Mark A. Burgman, recognized for studying expert decision-making within different fields of expertise states: "Face-to-face elicitation is effective if the number of questions is modest, usually no more than about 20-30, and the expert is available for the better part of the day." (Burgman, 2016, p. 104). Neither part is the case in this study. It is more effective to distribute questions and give people time to think about answers and reflect on questions on the basis of real-life situations. Many of the experts in our study found the task challenging still interesting because it forced them to reflect upon their decision-making basis. It would have been difficult or impossible to collect this much information in a face-to-face meeting or

direct observation with this number of participants, living in different countries, varying in educational background, and belonging to different avalanche decision-making "cultures".

The study aimed to investigate the knowledge and use of existing DMFs and the use and importance of their underlying factors amongst a purposefully selected group of experts. The study of the psychological aspects of decision-making requires separate studies.

After establishing differences between existing frameworks and experts' decision basis, the natural next step was to explore the possibilities of using a similar approach to that of the experts amongst backcountry skiers with varying competence. We investigated this by asking: *Does avalanche education affect the assessment and judgement of avalanche risk factors?* We found that the ability to assess avalanche risk factors is dependent on and improved with education. Further, the study shows that the relevance rating of avalanche risk factors amongst beginners is similar to that of experts. This implies that even non-experts could apply analytical, knowledge-based decision-making given the right education. The factors that were used in this study were selected purposely and set different requirements for the competence of the user. Probably there are differences in self-reported and actual in-field use and understanding of a factor. To clarify this, we would have to perform tests outdoors. It would have been nearly impossible to test an equivalent number of participants with varied educational backgrounds outdoors. The study does not try to show the difference between own reported and actual knowledge. On the other hand, the findings show that there is a potential for teaching something previously been thought to have been reserved for experts.

The avalanche forecast is a valuable source of information and represents an element in the decision basis. The third research question: *How do backcountry recreationalists use and understand different avalanche forecast elements?* guided the fourth study. A survey was used to obtain answers from an expert panel and recreational users and compare their understanding of the forecast. If the goal had been to study actual behaviour after reading an avalanche forecast, direct observation would be a valuable methodological approach.

The analysis showed that the forecast meets the needs of the end-user. However, competency and scenario complexity influence the effectiveness of the forecast. Based on the study's findings, the NAWs made changes to the forecast to provide the best possible basis for further assessments out in the field. The study confirms previous assumptions that the warning plays a central role in the decision-making process. As previously discussed, a common critique of using surveys is that it primarily attracts very engaged participants,

resulting in a skewed selection. However, this can be counteracted by targeting different user groups with different levels of competence, as done in this project.

Understanding the avalanche forecast and the translation into appropriate practice is always up for discussion amongst services that want to improve their product. Currently, a research collaboration between a cross-border forecasting service in Tirol (AUT), Süd Tirol and Trentino (IT) called *Euregio* and Simon Fraser University (CA) is studying the understanding of the forecast by the end-user. This project also asks whether the forecast conveys the most important information and investigates if the forecast affects risk management in the backcountry.

Avalanche experts worldwide agree on an increase in the number of backcountry recreationalists in recent years, involving new users and user groups. Thus, the need for training in the interpretation and use of avalanche warnings is possibly greater than ever. The number and diversity amongst users pose some challenges:

- The content of many avalanche forecasts is primarily tailored toward skiers, not communicating optimally to other groups such as ice-climbers, snowshoers, and snowmobilers.
- Not all backcountry skiers feel attracted to traditional avalanche education communities, such as alpine clubs, which have been an important mediator of the use of avalanche forecasts.
- Increasingly, both individuals and warning services share avalanche information on platforms, such as Instagram and Facebook. These have a format, with extensive use of photos and film, communicating in an appealing and easily understandable way, somewhat in contrast to the current avalanche forecast format.

To continue being the primary source of avalanche information and provide the best decision basis, at least for the trip planning phase, avalanche forecasting services must continuously re-evaluate *how* they convey the information, *what* this information contains, to *whom* they are communicating and if the receiver *understands* the message.

As mentioned, starting on my Ph.D. journey, my ambition was to develop and test a new decision model with the working title "Why is it safe - enough?" (WISE). Nevertheless, the first step was to study existing DMFs. I was not unfamiliar with existing models in the first place since I have both used and taught the use of several of them myself. However, in-depth insight into the decision-basis and understanding of the structure of existing DMFs lacked. Thus, the focus was changed, and I concentrated my research on studying decision

basis. On the other hand, I have never completely let go of the idea of WISE. As a mountain guide, I have used this question to be transparent and open about the decision basis towards my clients. Being a part of the research group at CARE, provided an opportunity to test any benefits of WISE beyond being transparent. So, the fifth and final study of this thesis was guided by the following research question: *Does the qualitative frame in the question eliciting the risk judgment influence the judged safety of scenarios of backcountry skiing in avalanche terrain?* Interestingly, we found that risk judgments framed in terms of safety result in more cautious, conservative judgments than when framed in terms of danger. Thus, when choosing to use an analytical decision-making approach, the user should be encouraged to ask, "why is it safe?" because it results in more cautious, conservative judgments. However, the actual in-field effect of asking this question requires further studies.

9.2 A broader perspective

Thematically this thesis belongs to the study of avalanche decision-making. This research area can be divided into studies of the decision basis (e.g., the individual factors used), studies of the decision process - various psychological aspects of decision-making (e.g., heuristics and group dynamics), and studies on how to improve decision-making quality in avalanche terrain (e.g., pedagogy and training strategies). Common to four of the studies in this thesis is that they examine various aspects of the basis in avalanche-decision making. Even if the framing study investigates a cognitive mechanism involved in the decision-making process, it has practical implications regarding the decision basis.

With an insight into the decision basis and an understanding of the decision environment, the foundation has been laid for future studies of the psychological aspects of avalanche decision-making and improvements thereof. The focus on the decision basis has been decisive for the literature used to answer the research questions in this thesis.

The first study was the study of the underlying factors of existing decision-making frameworks. The primary source is books and leaflets from the genre of avalanche safety literature. Frameworks described in books in German, French, English, and Norwegian were included in the study. Other frameworks may exist, but their prevalence is probably limited. It was always sought to analyse the latest version of a method. However, there may have been new versions that we were unaware of. The literature review unveiled each method's structure and the ideas behind the overall approach to the decision-making process. Most importantly, it led to the mapping and classification of the factors used in each framework. Each of the

identified factors was described and problematized in the light of literature relevant for each factor, such as books on snow science and snow science articles. For example, *The Avalanche Handbook* (D. McClung & Schaerer, 2006) was used to illuminate the uncertainty and relevance of factor *signs of instability* and a range of other factors that belong to snow science. Another example is factors belonging to the avalanche forecast category. These were problematized based on articles dealing with the possibilities and limitations of avalanche warnings i.e., (Müller, 2016; Nairz, 2010; Techel, Dürr, et al., 2016). The second study builds on the work in the first study and is based on the same literature.

In the third study of the thesis, relevant literature stems from fields of snow science and avalanche safety. However, when discussing the implications of the results, literature within decision psychology and learning was highly relevant e.g., (Helsdingen et al., 2011; Karpicke & Roediger, 2008; Gary Klein & Borders, 2016; Kuiken & Twisk, 2001).

The fourth study included literature on risk communication and literature that addresses different aspects of the avalanche forecast. The avalanche warning specific literature was chosen to understand the possibilities and limitations of the actual warning. When combined with the literature on risk communication, it formed the basis for interpreting the survey results and developing the specific changes made to the NAWs forecast.

The literature used in Study V is thematically divided into snow science, avalanche safety, and a comprehensive selection of literature regarding various aspects of framing. Especially relevant in this context are the articles on evidence sampling in relation to reference points.

These five studies have contributed to insight into the decision basis part of avalanche decision-making research. The next natural step is to use this insight to study the decision-making process and improve decision quality. There is little disagreement that avalanches are complex phenomena. I have always thought so too, which is one reason what makes it interesting to study. Through the study of the decision basis, I have delved into this complexity and gained an understanding of what the various aspects entail. On the one hand, one has all the factors that can be assessed and their complex interaction. Not a single factor alone shapes the avalanche risk, and not every factor is relevant in every situation, and there is uncertainty associated with their assessment. This is at the core of it being a complex environment. What makes it all even more challenging is that it is difficult and potentially

dangerous to learn from experience due to the wicked learning environment. This almost demotivating complexity and the uncertainty it entails motivated me to study decision-making research within other domains. The intention was to see if there is research from which avalanche decision-making can benefit. The study of decision-making literature from other domains enables me to see the decision basis research in a larger context. It also provides a good starting point for future studies and improvements of avalanche decision-making. Without listing all relevant literature, there are some articles and books that appear to be particularly relevant and that have shaped my thoughts regarding the improvement of avalanche decision-making:

Risk and uncertainty: Ralph Hertwig and colleagues on uncertainty and the adaptive toolbox (Hertwig et al., 2019), Mark A. Burgman on uncertainty and expert judgements (Burgman, 2016), and Ulkumen with colleagues on the dimensions of uncertainty. Kozyreva and Hertwig on uncertainty and ecological rationality (Kozyreva & Hertwig, 2019)

Heuristics and reasoning: Tversky and Kahneman's work on heuristics-and-bias (D. Kahneman, 2013; Tversky & Kahneman, 1972), Hertwig and colleagues on the heuristic mind (Hertwig et al., 2019), Gigerenzer and Gaissmaier on fast-and-frugal-heuristics approach (Gigerenzer & Gaissmaier, 2011) and Gigerenzer with colleagues on heuristics (Gigerenzer, 2014; Gigerenzer & Todd, 1999; Hafenbradl, Waeger, Marewski, & Gigerenzer, 2016), and Klein and colleagues on anticipatory thinking (G. Klein, Snowden, & Pin, 2011)

Skill development: Gary Klein and colleagues on training of cognitive skills and the gaining of insight (D. Kahneman, Klein, G., 2009; G. Klein, 2015; Gary Klein & Borders, 2016; Phillips, Klein, & Sieck, 2004), Robin Hogarth and colleagues on learning environment (R. M. Hogarth et al., 2015) and skill development and intuition (Hertwig, Hogarth, & Lejarraga, 2018; R. Hogarth, 2010a, 2010b), and Karpice & Roediger, Kuiken & Twisk, and Helsdingen and colleagues on how to improve learning (Helsdingen et al., 2011; Karpicke & Roediger, 2008; Kuiken & Twisk, 2001).

9.3 Quo vadis

All existing avalanche DMFs are developed with the best intentions – helping people to make better decisions. No decision-aid is perfect in every situation. They all have their flaws and shortcomings. An additional difficulty is that their use is complicated and not very

intuitive. There is a lot to be gained from making it easier for people to make better choices, especially when they can have serious consequences.

The Skitouren guru is an online tool that helps backcountry skiers to plan their outings. A list of trips is presented based on personal preferences (travel distance, trip difficulty, elevation gain). Each trip is assigned a risk level based on the current regional forecasted danger level. The trips are presented in a list ordered green (low avalanche risk), orange (elevated risk), and red (High avalanche risk). The Skitouren guru has become a popular trip planning tool recommended by the Swiss Council for Accident Prevention BFU. User data shows that the users predominantly chose green, low-risk trips. By offering a convenient solution that requires little effort from the user, it helps the user to select a low-risk option.

The Skitouren guru is a lot more sophisticated than other risk based DMFs. It uses an algorithm that classifies terrain better and more consistently than what is possible for humans. Also, it solves the problem of base rate neglect because it includes actual terrain usage (GPS-tracks) and thus can calculate relative risk. However, the risk-calculations suffer from sampling bias, analysis bias, and hindsight bias, like more traditional risk-based approaches.

The Skitouren guru is undoubtedly an appealing aid to many backcountry recreationalists. This and similar tools will evolve and improve parallel to technical development. Nevertheless, it is worth reflecting on some negative consequences. The use of such tools requires almost nothing of the user. No further information collection or deliberate reasoning regarding current conditions is required. The user ends up being unprepared for what will meet him or her out in the field: no knowledge of which cues to track or monitor; no idea about the distribution of critical weak layer; no insight into local differences that deviate from the forecast. This is most worrying because it is an awful starting point for dealing with unforeseen situations that typically deviate from what is expected. However, what is most provocative is that it builds up under the assumption that people are slaves to their whims, are lazy, stupid, and fallible, whereas computers are not.

In contrast to this view of human limitations in decision-making, there is another approach that values different aspects of decision-making competence and has a more positive view on human ability: empowerment. The objective is to empower people to make their own choices and exercise their own agency by fostering decision-making competence and

motivational competencies. An example of fostering such competence is learning the necessary skills and to exploit the appropriate heuristics.

9.4 Heuristics

When making decisions under various degrees of uncertainty, people often rely on heuristics (Gigerenzer & Todd, 1999; Hafenbradl et al., 2016). A heuristic is a simple decision rule that allows one to make judgments without integrating all the information available. When situations are complex and time is scarce, these simplifications support humans coping with their limited capacity to process information.

One major concern, especially in situations where decisions can have severe consequences, is research showing that heuristics can result in biased thinking and errors. McCammon showed this in his study of avalanche accidents (I. McCammon, 2004), and there is a rich body of research showing this in other domains (D. Kahneman, 2013). This research is done from a heuristics-and-bias perspective that focuses on understanding the cognitive processes underlying human judgment by observing biases and errors.

Not all heuristics perform equally well in every environment. Rather, people rely on a set of heuristics and choose an adequate one from what is termed the adaptive toolbox. When there is a good match between the environment and the heuristic used, it is ecologically rational. Hence, when relying on an ecologically rational heuristic, people are able to arrive at satisfactory decisions in a short time and based on little information. One heuristic that is used by experts in many applied domains is fast-and-frugal decision trees. The use of this heuristic ranges from emergency medicine to military decision-making (Banks, Gamblin, & Hutchinson, 2020; Gigerenzer & Gaissmaier, 2011). Fast-and-frugal decision trees heuristics aids decision-making based on the assessment of a small number of cues. Each cue either leads to a decision or a continued search. The decision structure of this heuristic agrees well with the one used by experts in avalanche decision-making identified in Study II. Together with core avalanche factors/cues identified in Study I, it would be possible to design a fast-and-frugal decision tree.

10 Conclusions

This thesis contributes to our understanding of existing decision-making frameworks and provides new knowledge about the decision basis and ways to improve decision quality. It provides research that can be translated into actionable and practical measures. Moreover, it provides a foundation for future avalanche decision-making research intending to improve decision quality. More specific, it shows large differences in the number of factors, which factors are used and the overall approach to decision-making between the different existing frameworks and between the frameworks and expert decision-making. This provides a previously non-existing foundation to improve our decision basis. Further, this research substantiates that the analytical approach, previously been thought to be reserved for experts, could be applied by other user groups given the right education. It also confirms the importance of the avalanche forecast and suggests that most users find the warning well suited for their needs. Finally, it demonstrates that risk judgments framed in terms of safety result in more cautious, conservative judgments than when framed in terms of danger. Thus, framing could be exploited in both avalanche risk communication and future decision-making frameworks.

All existing DMFs follow a structure, which is how the user should ideally make decisions in the developer's opinion. Future studies on decision-making in avalanche terrain should consider how people are able to make decisions.

Backcountry skiing has become an increasingly popular and important tourist industry. This development is linked to an international trend where sports involving risk-exposure have become more popular than ever. For the accident figures not to follow the same abrupt development, we must facilitate high-quality decision-making amongst those who travel in avalanche terrain. This thesis contributes to just that. This thesis is also relevant to other application and science domains, where decisions are made under uncertainty and feedback is sparse, misleading, or lacking.

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Appendix

The original peer reviewed papers (I, II, IV, V) and the submitted manuscript (III) are presented in the same order as the studies. The additional popular science articles associated with paper I, II, V are presented at the very end.



Avalanche decision-making frameworks: Classification and description of underlying factors



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ABSTRACT

Snow avalanches are a complex phenomenon and correctly assessing avalanche danger is crucial in order to avoid accidents. To aid the decision-making process, different decision-making frameworks (DMFs) have been developed. However, each DMF assesses different factors. We identified 44 factors included in the ten most commonly used DMFs, supplemented by nine factors regarded as important by avalanche professionals, resulting in 53 factors. We classify and describe each factor's possible strengths, weaknesses and limitations. Many factors are shared by the DMFs, but there are differences when it comes to type of factor and emphasis. The number of factors used by the different DMFs varies from 11 to 31. 81 out of 100 experts who participated in our survey use > 33 factors in their decision-making, and regard other factors as more important than the ones emphasised in most DMFs. We discuss the usage of the factors and provide recommendations. Our classification and description of the factors contribute to a better understanding of why the developers of the different DMFs have included them in their frameworks. This is fundamental for a better understanding of expert use or lack of use of DMFs, and why some DMFs or single factors are preferred to others.

1. Introduction

1.1. Avalanches and decision making

Snow avalanches are a hazard to people in mountainous regions around the world (Furset, 2006; Lied and Kristensen, 2003; Techel et al., 2016a). The victims are, workers, skiers, snowboarders, snowmobilers, snowshoers, soldiers, climbers, hikers, mountain guides and rescuers. The annual fatality rate within Europe and North America is about 140 (Techel et al., 2016a; Brugger et al., 2007; Boyd et al., 2009). Between 80% and 90% of fatal accidents amongst backcountry users were triggered by the victims or someone in their party (Harvey et al., 2018; McCullung and Schaerer, 2006a; Schweizer and Litschig, 2000). Correctly assessing avalanche danger is crucial for avoiding accidents, and this becomes even more important as the number of people using mountain areas for recreation increases.

Researchers and avalanche experts have developed a range of avalanche decision-making frameworks (DMFs) to support the decision-making in avalanche terrain and reduce risk. Some frameworks structure the decision-making process, whereas others conclude with a go or no-go decision. However, each DMF assesses different factors in the decision-making process.

In this article we examine the ten most commonly-used approaches in Europe and North America. The selection is based on recommended frameworks from national umbrella organisations such as the Swiss core training team for avalanche education (www.slif.ch, KAT) or the Canadian Avalanche Association (CAA), and methods being taught by mountain guide associations, alpine clubs and educational institutions. Other accessible methods exist, but those considered here are the ten most commonly taught and used.

1.2. Objectives

This study is part of a larger research project on decision-making in avalanche terrain. Here, we present a classification of the assessment factors, not an analysis of the decision-making process itself. The objectives are (a) to identify the underlying factors in existing decision-making frameworks, (b) analyse which of these factors are shared amongst several frameworks, and (c) assess which of these factors, and any others are used by experts.

By classifying and describing each factor their possible strengths, weaknesses and limitations become apparent. Since the aim is to assess which factors the experts consult at different stages in their decision-making process, we and an avalanche expert advisory board, identified

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further relevant factors not included in the DMFs, such as different stability tests and information from the avalanche forecast. Finally, we asked a panel of one hundred avalanche experts about their use and opinion on the importance of each factor, presented in detail in the companion article (Landrø et al., 2019, this issue). These two articles represent the first step in examining and comparing different DMFs in this way. Future research will analyse the decision-making process itself, amongst experts and backcountry users.

Given the complexity of this material we have chosen to present it in two accompanying articles. This article provides a classification and analysis of the factors used in avalanche DMFs and factors used by experts. A complementary article presents the experts' knowledge and use of the DMFs and their underlying factors.

1.3. Development of avalanche decision-making frameworks

In 1916, Matthias Zdarsky published his “Elemente der Lawinenkunde” (“Elements of avalanche knowledge”), stating that slope angle, molecular strength and the weight of the snow are essential elements in the release of avalanches (Zdarsky, 1929). This is seen as the starting point of documented practical knowledge about snow and avalanches, leading up to today's decision-making frameworks.

By 1930, the fundamental knowledge concerning snow and avalanches was available for backcountry travellers (Höllner, 2016). In the 1940s and 50s, the research focus was on layering and snow metamorphosis, leading to a snow hardness scale and the first international Snow Classification in 1954 (Schaefer et al., 1954). In the following years, snow cover and stability tests, such as Die Norweger Methode (“the Norwegian method”) by Nils Faarlund (Kellermann, 1990) and the Compression test (Jamieson, 1999) were developed, thus providing the important aids for backcountry travellers.

Previously, there was little structure in the evaluation and no decision aids existed. This changed when Swiss mountain guide Werner Munter introduced the 3×3 in the 1980s (Munter, 1991), initiating the development of today's use of a range of different frameworks.

2. Methods and data

2.1. Ten decision-making frameworks used in the study

We focus on ten widely used decision-making frameworks. These are; The 3×3 (Munter, 1997), The Reduction Method (Munter, 1997), Stop or Go (Larcher, 1999), Snow-card (Engler, 2001), The Graphic Reduction Method (Harvey et al., 2012), The After Ski Method (Brattlien, 2014), NivoTest (Bolognesi, 2000), ALPTRUTH (McCammon, 2006), The Avaluator 2.0 (Haegeli, 2010a), and The Systematic Snow-cover Diagnosis (Kronthaler, 2003). A brief description follows of each of these frameworks.

2.1.1. The 3×3

The 3×3 (3 filter \times 3 criteria) is a structured approach to avalanche evaluation. By use of guided questions this method evaluates three main factors 1) avalanche conditions, 2) terrain and 3) human factors. These factors are evaluated across three stages; 1) Regional/trip planning, 2) local/visible area and 3) zonal/slope specific. The 3×3 is an integrated part of the Reduction Method and is often used in combination with other frameworks. It should not be regarded as a DMF itself, but more as an overarching structure to organise the decision-making process at different stages.

2.1.2. Reduction method (RM)

The Reduction method (RM) developed by Werner Munter (Munter, 1997) is based on an equation that balances the danger potential against reduction factors. The danger potential is an expression for the probability of hitting a weak spot and triggering an avalanche at each danger level. It is based on a comparison of stability test results

(Rutschblock tests) and danger level. According to Munter's calculations the danger potential increases exponentially for each danger level. To reduce risk different safety measures, so-called reduction factors, can be applied. The values of these reduction factors were calculated using data from fatal avalanche accidents in Switzerland. The weight of these factors mirrors Munter's ambition to reduce the amount of avalanche fatalities by 50% from their 1997 levels – a level that would equal accidents in hiking or driving a car, according to Munter.

This accepted residual risk is defined by the ratio of danger potential and the reduction factor. Danger potential is thought to be 2^D (D being the current danger rating), i.e. danger level 3 corresponds to danger potential 8. The reduction factors (RF) are categorised into three classes: RF1 slope angle, RF2 slope aspect, elevation and travel frequency, and RF3 group size and management. Within each class, they have different values, for example, for a slope less than 35° the calculated RF is 4, whereas for the avoidance of north-facing slopes the RF is 2, and for a small group the RF is 2. The reduction factors are then combined and the residual risk is quantified with the equation

$$\text{Residual risk} = \frac{\text{Danger potential}}{\text{Reduction factor} * \text{Reduction factor} * \text{Reduction factor}} \leq 1$$

According to Munter, the accepted residual risk should be ≤ 1 . The RM and 3×3 are complementary tools that have to be combined to achieve acceptable residual risk.

Munter (Munter, 2003) later introduced several other simplifications of the Reduction Method, such as the Elementary Reduction Method (ERM), to attract novice users. ERM focuses exclusively on terrain restrictions based on combining danger level and inclination.

2.1.3. Stop or Go (SoG)

Stop or Go (SoG) was introduced by Michael Larcher (Larcher, 1999) that has a framework similar to the RM, and uses Munter's risk calculations, but omits the mathematical equation that is used in the RM. The method consists of three components. In check 1, the ERM is applied. In check 2, Larcher added recognition and assessment of what is thought to be the five most crucial contributors to avalanche hazard: new snow, wind-deposited snow, recent avalanches, water saturation and collapsing weak layers making “whumpf” sounds; followed by the question: “are the observed conditions a threat to the group?” Check 3 is similar to the 3×3 method in addition to hazard mitigation measures, such as transceiver testing and keeping a safe distance of 10 m apart on slopes steeper than 30° when ascending.

2.1.4. Snowcard (SC)

The SnowCard (SC) method is also derived from Munter's original Reduction Method. The developer, Martin Engler, made a limited statistical study on avalanche incidents, confirming Munter's findings on exponential growth of the risk potential from one danger level to the next. The objective of SC is to determine average risk based on the danger level provided by the avalanche warning, inclination and a distinction between “favourable” and “unfavourable” aspects and elevation bands (Engler, 2001).

Decision-making using SC is done in two stages. In the first stage a graphic version of the ERM showing risk sequences from green to yellow to red is used. The card has a hologram such that the sequences change when the card is tilted depending on whether a slope is considered favourable or unfavourable according to the avalanche forecast. In the second stage, out in the terrain, SC takes level of competence into account. Level one (basic) resembles the avalanche danger assessment done in check 2 in the SoG. In level two (advanced and expert), different parts of the “Factor Check” are used. The “Factor Check” is a checklist for examining the proposed main factors contributing to avalanche incidents. It is used to adjust the local danger level, thus allowing the experienced user more flexibility when it comes to terrain choice.

In later years SC has become an integrated part of the “Lawinen-

Mantra” (Avalanche Mantra) that adds a checklist to the original SC: 1) risk assessment using the SC (as before), 2) Analytic assessment if practical given current avalanche problem, 3) Take gut feeling and human factors into account, 4) Evaluate the consequences, 5) Take sensible safety precautions (Mersch & Behr, 2018).

2.1.5. Graphic reduction method (GRM)

The Graphic Reduction Method (GRM) is another type of reduction method. In the GRM, a risk-check is performed that combines danger level and inclination (Harvey et al., 2012). According to the GRM, the danger level outside the core area (aspect and elevation band given in the forecast) can be reduced by one level. As in the SC, GRM works with the concepts of favourable and unfavourable slopes, but other factors are not taken into account. Also similarly to the SC, the status of the GRM is reduced in route selection and slope specific decision-making for the advanced user. The focus is on evaluation of avalanche conditions, terrain and the human aspect. Avalanche patterns, as used in the avalanche forecast, play an important role (Harvey and Nigg, 2009). However, no structured approach for evaluating these factors is provided.

2.1.6. After ski method (ASM)

The Norwegian After Ski Method (ASM) is similar to the GRM. The difference is a 5° reduction in inclination in relation to danger level (Brattlien, 2014). The ASM recommends avoiding slopes steeper than 30° at danger level 3 – considerable, compared with 35° in the GRM and ERM. The inclination reduction is done to achieve a greater risk reduction. Using the same data set as the one used in (McCammon and Hægeli, 2005) the preventative effect of these terrain recommendations is 93% according to Brattlien (2014).

2.1.7. Nivotest (NT)

The NivoTest is designed for an assessment of the avalanche risk without using an avalanche forecast. Based on 25 yes/no questions regarding weather, snowpack, avalanche activity, route and participants the user can calculate risk for a specific route or terrain (Bolognesi, 2000). Each of the first 20 questions is weighted based on a statistical analysis of > 7000 actual cases. The last five questions are based on the developer's experience. After answering all questions, the result of the avalanche risk assessment is shown in the form of one of three icons: smiley face, uncertain face or sad face.

2.1.8. Checklist sum obvious clues ALP TRUTH (AT)

ALP TRUTH (AT) is the acronym for the seven clues included in the checklist for this method: Avalanche, Loading, Path, Terrain traps, Rating, Unstable snow, Thaw instability (McCammon, 2006). The user adds up the number of obvious clues for the slope in question. If two or fewer obvious clues are observed, normal caution is recommended. With three or four obvious clues present, extra caution is advised. When observing five or more obvious clues, skiing is not recommended.

2.1.9. Avaluator 2.0 (A2.0)

As with SC and GRM, the Avaluator 2.0 (A2.0) has a graphic representation of the estimated risk (green = caution, yellow = extra caution and red = not recommended). Unlike the different reduction methods that combine inclination and danger level, this recommendation is based on an avalanche condition score and a terrain characteristics score. Each factor that constitutes the avalanche condition and terrain characteristics is given a weighting value, e.g. signs of instability: +1, Slope steeper than 35°: +2. The user evaluates the different factors and ends up with a score for avalanche conditions and terrain characteristics. The estimated risk is read from a classic risk matrix, giving one of the initial three categories (Haegeli, 2010b).

2.1.10. Systematic snow-cover diagnosis (SSD)

The Systematic Snow-cover Diagnosis (SSD) is a purely analytical

framework (Kronthaler, 2003; Kronthaler and Zenke, 2006; Kronthaler, 2019). It uses three steps to come to a decision. Step one: finding the most prominent weak layer and testing the weak layer - slab combination using the Small Block Test (SBT). This is followed by an evaluation of four weak layer properties (Kronthaler, 2019). The SSD uses many of the same factors as the threshold sum approach when evaluating snow layer properties. Properties that are regarded as unfavourable are: smooth fracture upon light lateral tapping; weak layer is thin (≤ 3 cm) and consists of large crystals (> 1.25 mm); weak layer is within one metre of the snow surface; the overlying snow is soft. Step two: Process thinking, consider the processes that led to the weak layer slab combination observed and distribution of this combination. Step three: Assessment of the situation using a systematic structure of questions and YES or NO answers (loose or slab avalanche; natural release; release by a single skier; release with high additional load; no weak layer). This leads to an interpretation aid that ends with three different recommendations regarding cautions (red: avoid, keep distance to slope, not over 30°; yellow: one-by-one, safety distance; green: standard measures).

2.1.11. Scope

In our presentation of the different DMFs we have focused on the key factors, and given a brief review of the frameworks' overall approaches (analytical or probabilistic), and workflow. The decision-making process within the frameworks is beyond this scope of this article.

2.2. Reasoning methods to assess avalanche risk

Assessing avalanche risk requires integrating a range of factors (Table 2) that are often derived from partial observations, that themselves are uncertain, and is further impeded by the complexity of the interaction between the factors. Strictly speaking, neither deductive nor inductive reasoning is appropriate. Accordingly, reasoning is abductive, i.e. from incomplete observation one makes a best prediction of the avalanche risk, related to but not identical with using a heuristic approach. Abductive reasoning requires deliberate reasoning and is often more challenging than deductive or inductive reasoning. Indeed, the frameworks often use elements from the deductive and inductive approaches to accommodate the abductive approach. To reduce abductive reasoning and exploit deductive reasoning, Munter's method assesses the avalanche risk during the different phases of an outing by providing a set of instructions based on risk calculations. Munter called this approach probabilistic (Munter, 1997). In McCammon and Hægeli (2005) terminology, Munter's probabilistic approach corresponds to rule-based decision-making. (See Fig. 1)

Most DMFs have components from both approaches, i.e. operating with numerical thresholds and checklists to aid in the decision-making process (Table 1).

2.3. Direct and indirect factors

The frameworks are often presented by use of a plastic-coated card or checklist that can be taken on a trip. The factors printed on these cards constitute the basis for making the decision. We refer to these as direct factors. Examples are the six avalanche condition factors (Regional Danger Rating, Persistent Avalanche Problem, Slab Avalanches, Signs of Instability, Recent Loading, and Critical Warming) and four terrain characteristics factors (Slope steepness, Terrain Traps, Slope Shape, Forest Density) printed on the plastic-coated card that comes with the A2.0.

In addition to the plastic-coated card or checklist, most DMFs have some accompanying literature. This can be books or leaflets where the DMF is explained and factors beyond the direct factors are presented. The leaflet Caution Avalanches! (Harvey et al., 2018) that accompanies the GRM, is such an example and gives group management and

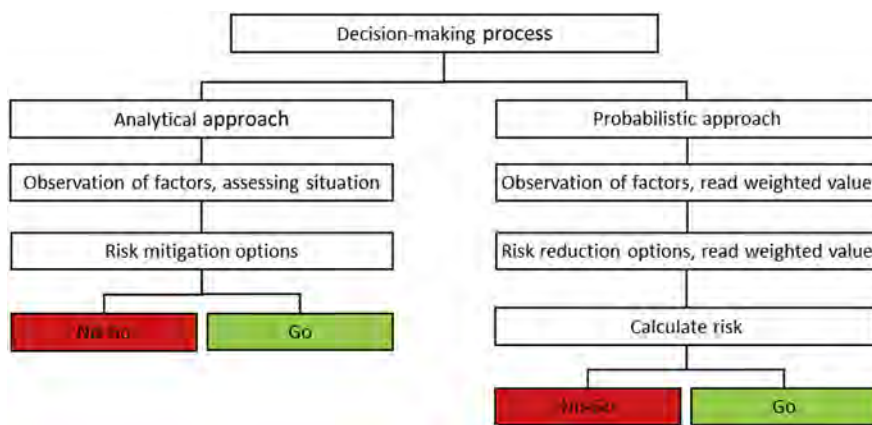


Fig. 1. Illustration of the overall decision-making process in analytic and probabilistic DMFs.

snowpack evaluation factors as well as others. We use the term *indirect factor* when referring to these since they can be regarded as part of a framework, but do not belong to the direct factors on the cards or checklists.

2.4. Data on underlying factors in avalanche decision-making frameworks

We collected the factors included in the checklists, cards or as described in the accompanying literature belonging to the different frameworks. This resulted in 44 different factors. Two of these 44 factors are found in the avalanche forecast, namely the *danger level* and *most exposed height level and aspect*. However, in order to examine whether experts use the forecast we included five additional elements from the avalanche forecast; 1) main message, 2) avalanche problem, 3) mountain weather, 4) snowpack information and 5) travel and terrain advice. Next, we included one factor describing the most used stability tests, because in our experience, their use is quite common amongst experts and they are featured in the literature accompanying some of the DMFs.

The factors were then incorporated into a survey and pretested on a panel of 10 avalanche experts of different nationalities and professional backgrounds. The participants provided instant feedback via online video or in person. Based on the feedback from the pretest we added three additional factors (*how snow feels when moving on skis; avalanche sensitivity to triggering; avalanche type*). This resulted in 53 factors that are grouped thematically into five categories (Table 2).

2.5. Data from expert survey

100 people (including 10 women), considered experts according to Dreyfus & Dreyfus (2005), completed over 90% of the survey. The respondents were from Scandinavia (n = 32), the German-speaking part of the Alps (n = 32) and North America (n = 35). On average, respondents had 28.2 years of experience in backcountry skiing and spent

Table 1

The ten most common avalanche decision frameworks with description of region of origin, approach (terminology from Munter) and number of included factors.

Framework	Region	Go / no go decision rule	# Factors	Reference
3x3	Alps			(Munter, 1997)
Reduction method (RM)	Alps	Probabilistic. Calculation	15	(Munter, 1997; Munter, 2009)
After ski method (ASM)	Norway	Probabilistic	18	(Brattlien, 2014)
Snow-card (SM)	Alps	Probabilistic ^a	29	(Engler, 2001)
Stop or go (SoG)	Alps	Probabilistic ^a	31	(Larcher, 1999)
NivoTest (NT)	Alps	Probabilistic. Adding and weighting of factors	27	(Bolognesi, 2000)
Avaluator 2.0 (A2.0)	CA	Adding and weighting of factors, probabilistic ^a	27	(Haegeli, 2010a)
Graphic Reduction method (GRM)	Alps	Probabilistic ^a	31	(Harvey et al., 2012)
ALPTRUTH (AT)	North-America	Adding of factors	11	(McCammon, 2006)
Systematic snow-cover diagnosis (SSD)	Alps	Analytic	27	(Kronthaler, 2003; Kronthaler et al., 2013)

^a = Includes elements of analytic/deductive avalanche assessments.

Table 2

Categorisation of factors used in ten avalanche decision frameworks in this study.

Category	Number of factors
A. Snow and avalanche	13
B. Snowpack evaluation and stability test	10
C. Avalanche forecast	7
D. Group and group management	13
E. Terrain	10

50 days backcountry skiing per season of which 73% were in avalanche terrain. The experts rated the 53 factors in terms of use and importance (decisive, relevant or irrelevant). Tables 3–7 present how many of the experts consider each factor as being decisive in their decision-making in at least one of the three stages. For more details please see the accompanying article (Landrø et al., 2019).

3. Results

The mapping resulted in 53 different factors, and the frameworks include between 11 and 31 factors. Several factors are shared amongst the frameworks (see Tables 3–7), but differences in type and number of factors are prevalent. The factors are grouped thematically into five categories (Table 2), which is also used to structure the presentation and discussion of the results. Further results from the expert evaluation are presented in the accompanying article (Landrø et al., 2019).

3.1. Snow and avalanche factors

Category A (Snow and avalanche) factors are indicators of snow instability and they can be observed in the terrain. In avalanche forecasting observations of these factors are divided into three classes; 1)

Table 3
Snow and avalanche factors by framework and expert usage.

	Direct factor in DMF	Indirect factor in DMF	# use	# decisive	as %
Signs of instability	SoG, AT, A2.0	RM, ASM, SC, GRM, SSD	73	62	85
Loading of new snow	SoG, NT, AT, A2.0	RM, ASM, SC, GRM, SSD	73	54	74
Wind or rain within last 48 h	NT, A2.0	RM, ASM, SC, SoG, GRM, AT, SSD	74	53	72
Critical warming	AT, A2.0, NT	RM, ASM, SC, SoG, GRM, SSD	80	65	81
Signs of slab avalanches within last 48 h	SoG, AT, A2.0, NT, GRM	RM, ASM, SC, SSD	73	50	68
Presence of persistent or deep persistent slab problem(s)	A2.0	RM, ASM, SC, SoG, GRM, NT, SSD	79	66	84
Unusual, infrequently travelled route	NT	RM, SC, SoG, GRM, SSD	53	18	34
Pillows wind-drifted snow/cornices	SoG, NT	RM, ASM, SC, GRM, AT, A2.0, SSD	68	54	79
Deep snow		RM, ASM, SC, SoG, GRM, NT, AT, A2.0, SSD	67	30	45
How snow feels when moving on skis			78	39	50
Potential avalanche size			70	50	71
Avalanche sensitivity to triggering			77	59	77
Possible avalanche type (loose snow, slab avalanche)			75	52	69

Legend. RM = Reduction Method, ASM = After Ski Method, SC = Snow-card, SoG = Stop or Go, NT = NivoTest, A2.0 = Avaluator 2.0, GRM = Graphic Reduction Method, SSD = Systematic Snow-cover Diagnosis, AT = ALPTRUTH. Last three columns: number of experts stating that they use the factor, state it being a decisive factor in any of the 3 stages (planning, route, or slope), and the percentage.

Table 4
Snowpack evaluation in DMFs and by experts.

	Direct factor in DMF	Indirect factor in DMF	# use	# decisive	as %
Hardness of overlying snow (over weak layer)	SSD	SC, SoG, GRM	78	23	29
Weak layer distance from snow surface	SSD	SC, GRM	80	23	29
Weak layer grain type	SSD	SC, GRM	70	19	27
Hardness difference between layers	SSD	SC, GRM	38	17	45
Weak layer thickness	SSD		62	15	24
Grain size of weak layer	SSD		58	17	29
Fracture character	SSD	A2.0	75	16	21
Test score from stability test(s)	SSD	GRM, A2.0	38	9	24
Stability tests (CT, ECT, hand shear, little block, PST, Rutschblock, ski cut)	SSD (little block)	GRM, A2.0	92	11	12
Combination of different elements	SSD	SC	N/A		

For abbreviation see Table 3.

Table 5
Avalanche forecast factors by DMF and expert usage.

	Direct factor in DMF	Indirect factor in DMF	# use	# decisive	in %
Danger level	RM, ASM, SC, SoG, GRM, A2.0	AT	66	26	39
Main message		SoG	65	21	32
Most exposed height level and aspect	RM, SC, SoG, GRM, A2.0	SSD	66	35	53
Avalanche problem(s)	A2.0	SoG, GRM, SSD, (NT*)	86	47	55
Mountain weather forecast		SC, GRM, A2.0	75	28	37
Snow pack information		SC, SoG, GRM, A2.0, SSD	81	30	37
Travel and terrain advice			21	1	5

For abbreviation see Table 3.

Table 6
Group factors and group management by DMF and expert usage.

	Direct factor in DMF	Indirect factor in DMF	# use	# decisive	in %
Group size (small, large, very large)	RM, SoG	SC, GRM, NT, SSD	98	65	66
Participants with low technical skills	NT	ASM, SC, SoG, GRM, SSD	99	69	70
Participants in bad physical shape	NT	ASM, SC, SoG, GRM	97	63	65
Group not trained in avalanche rescue	NT	ASM, SoG	99	77	78
Participants with avalanche safety equipment	SoG, NT	ASM, GRM, A2.0	99	53	54
One-at-a-time exposed	-	-	75	39	52
Ski at a distance	-	-	57	21	37
Clear directions / plan on where and how to ski	SoG	SC, GRM	84	58	69
stopping at safe spots	A2.0	ASM, SC, GRM	94	53	56
10 m distance from 30° ascending	SoG	SC, GRM, A2.0, SSD	34	10	29
Safety distance ascending		RM, ASM, SC, SoG, GRM, A2.0, SSD	59	17	29
30 m distance when descending	SoG	SC, A2.0, SSD	27	9	33
One-at-a-time from 35° when descending	SoG	SC, A2.0, SSD	28	7	25

For abbreviations see Table 3.

Table 7
Terrain factors by DMF and expert usage.

Category: Terrain factors	Direct factor in DMF	Indirect factor in DMF	# use	# decisive	in %
5° intervals from 30°	RM, ASM, GRM, SC, SoG	A2.0	28	17	61
Danger level/slope inclination	RM, ASM, GRM, SC, SoG		18	12	67
slope between 34 and 36 degree steep			26	14	54
Discriminating between AT /no AT	SSD	NT, A2.0	86	61	71
ATES	A2.0		72	8	11
Use of favourable terrain formations	SoG	GRM, A2.0	94	59	63
Avoiding terrain traps	AT, A2.0	ASM, SC, GRM	95	59	62
Forest density		SoG, AT, A2.0	71	10	14
Convex or unsupported slopes	NT, A2.0	SC	83	45	54
Avoiding known avalanche paths	AT	A2.0	81	19	23
Avoiding exposed routes without protected areas	NT	GRM	88	41	47

For abbreviation, see Table 3. AT = avalanche terrain.

Instability factors; 2) Snowpack structure, and 3) Snow and weather factors at the snow surface, where class 1 factors are the most significant indicators of avalanche danger (MCClung and Schaerer, 2006b). Except for the three factors regarding avalanche type, size and sensitivity to triggering, which are presented at the end, we have grouped our factors according to this three-class division.

We identified 13 factors in this category, of which four are not part of any decision-making framework, but have proven to be important in expert avalanche decision-making (Landrø et al., 2019).

3.1.1. Factor 1: signs of instability

In addition to recent avalanches, other signs of instability such as collapsing, whumpfs, cracks and drum-like sounds, are easy accessible information. Signs of instability (class 1) are regarded as direct evidence of snow instability and avalanche danger, and there is little uncertainty associated with their interpretation (MCClung and Schaerer, 2006a).

3.1.2. Factor 2: loading of new snow

The loading of new snow is directly associated with meteorological factors (class 3) such as the amount of new snow, precipitation intensity and wind speed. These related factors are less direct evidence in evaluating snow instability (MCClung and Schaerer, 2006a). Loading of new snow will add extra weight to the existing snowpack, potentially increasing stress and instability. However, this is again dependent on the amount of snow, precipitation intensity and wind speed. Its actual effect concerning instability is also heavily dependent on the stability of the old snowpack and the snow surface before the loading. The interaction of these factors is decisive for factor loading of new snow's relevance in avalanche danger assessment. However, the use of this factor in avalanche decision-making depends on interpretation, and carries uncertainty.

3.1.3. Factor 3: occurrence of wind or rain within the last 48 h

The evaluation of wind and rain relies on interpretation and is not direct evidence of snow instability. Wind belongs to class 3 whereas rain (precipitation type) belongs to class 2. As well as new snow, wind (snow drift) and rain will also add extra weight to the existing snowpack. Rain can weaken bonding within the snowpack thus reducing its strength and potentially increasing stress and instability.

3.1.4. Factor 4: critical warming

Rapid increases in temperature will affect snow metamorphism, reduce strength by weakening bonding within the snowpack and increase stress and instability by affecting the continuous downhill moment of snow called snow creep. When critical warming occurs in combination with snowfall and wind it is commonly referred to as "avalanche weather" due to a high likelihood of avalanches under these conditions. This is also a class 3 factor needing careful interpretation and is accompanied by uncertainty.

3.1.5. Factor 5: signs of slab avalanches within the last 48 h

Signs of slab avalanches are easy to observe and are direct evidence of snow instability (class 1). There is little uncertainty associated with their interpretation. However, the time of release may be very difficult to determine under certain conditions in some environments. Some avalanche situations stabilise rather quickly, whilst others last for weeks, affecting the importance of this factor in each case.

3.1.6. Factor 6: presence of persistent or deep persistent slab problem(s)

Weak layers are a class 2 factor. Persistent weak layers can form at the snow surface (surface hoar) or in the snowpack and also near the surface due to a high temperature gradient (1 °C / 10 cm) (facets and depth hoar). Deep persistent slab problems often involve thick and hard slabs, and there are often no visible or audible signs of this kind of instability. There is a lot of uncertainty related to weak layers and especially to persistent weak layers. It is probably the hardest avalanche problem to manage in a consistent way, and is sometimes referred to as an expert trap. Common advice is to be very conservative in terrain choice. Avalanches that release on these kinds of layers have the potential to be large, cross-terrain barriers and can have multiple slide paths. Remote triggering and releasing above the trigger are common. This problem stabilises slowly, if at all, and potentially can last an entire season. Depending on the conditions that created this layer, it can be localised at specific elevations and aspects.

3.1.7. Factor 7: unusual, infrequent travelled route

Frequent skiing may have a stabilising effect on the snowpack. If a slope is skied during or directly after every snowfall, this will affect bonding between layers, and the distribution and development of weak layers. This means that the part of the slope that is heavily tracked will be more stable than adjacent parts that are not tracked or less tracked. Exceptions to this stabilising effect are snowpacks with deep persistent weak layers and very wet snowpacks. This factor is approached differently amongst the different DMFs. The NT rates *unusual, infrequent travelled route* as negative, giving it 1, max 2 points, whereas in several other DMFs, such as RM, this factor is not rated at all but instead frequently travelled slopes are rated as positive, giving it a reduction factor of 2 (Munter, 2009; Bolognesi, 2013).

3.1.8. Factor 8: presence of pillows of wind drifted snow or cornices

When snow is transported by wind, rolling and saltation will decrease snow crystal size considerably. These small crystals will sinter and form cohesive snow layers (dense- or soft-cohesive slab) in lee areas. Pillows of wind-drifted snow and cornices are the result of wind-transported snow and hence say something about wind strength and direction. The pillows indicate extra weight on the existing snowpack, increasing stress and instability to the old snowpack in addition to potentially being a slab in itself. Cornices indicate wind direction and, if they collapse, act as an avalanche trigger to the possible unstable slope below. The evaluation of this factor involves uncertainty and does not

provide direct evidence of snow instability. This factor is associated with the factor loading of new snow (class 3).

3.1.9. Factor 9: deep snow

This factor is an indicator of several danger assessment criteria: amount of snow available for wind transportation; ability of the snowpack to support a certain load; avalanche type and potential size; additional load on the existing snowpack. Like the other class 2 factors, it requires careful interpretation, is not free of uncertainty and provides no direct evidence of snow instability.

3.1.10. Factor 10: how snow feels when moving on skis (additional factor, not part of a DMF)

Observing how snow feels when moving on skis can be an important source of information. Experts note crystal forms on the surface, surface roughness, hardness or if the snow is dry, moist or wet, fracture propagation, amount of new snow and its density, how deep one penetrates and, possibly most important, changes in surface snow. This information can be important in determining avalanche type, potential avalanche size and the likelihood of triggering an avalanche. This factor belongs to class 3: Meteorological Factors - surface condition (MCCLung and Schaeerer, 2006a).

3.1.11. Factor 11: potential avalanche size (additional factor, not part of a DMF)

Avalanches are classified into five categories according to size; 1-small, 2-medium, 3-large, 4-very large and 5-extremely large¹ (EAWS (2019)). In the process of decision-making, this factor is mainly of interest with regard to possible consequences of a release, i.e. potential avalanche size big enough to be of great consequence on a specific slope. Potential slab avalanche size is an estimate built on different combinations of inclination, terrain formation, weak layer, slab thickness, slab stiffness and amount of snow carried along. Potential loose snow avalanche size is estimated by a combination of inclination, terrain formation and amount of accessible loose snow in the avalanche path. In size 1, small avalanches, there is minimal danger of burying. These avalanches will typically stop before the end of a slope. However, depending on terrain, there can be a risk of falling or being carried over cliffs. Size 2, medium, is defined as avalanches that can bury, injure or kill a person. Thus any avalanche larger than size 1 may easily become fatal.

3.1.12. Factor 12: avalanche sensitivity to triggering (additional factor, not part of a DMF)

The sensitivity to triggering describes how easy it is to trigger an avalanche, distinguishing between natural and human triggered avalanches. This factor is part of the workflow when determining danger level in an avalanche forecast when using the Conceptual Model of Avalanche Hazard (Statham et al., 2018) or ADAM (Müller et al., 2016). The sensitivity ranges from unreactive or very hard to trigger to touchy or very easy to trigger. Under unreactive conditions there is no or only a minor avalanche problem, no distinct weak layers and the fractures are hard to initiate or do not propagate. In the touchy condition there is at least one avalanche problem, one or several well-developed weak layers and the fractures can be initiated with low additional load, such as one single skier, and propagates well. Remote triggering is typical.

3.1.13. Factor 13: avalanche type (additional factor, not part of a DMF)

Avalanche type is not included in the process of determining danger level, but due to the differences between slab and loose snow

¹ Note that as of winter season 2018–2019 the EAWS (European Avalanche Warning Services) has agreed on implementing new names for the different categories. The changes are meant to improve the effectiveness of the avalanche warnings because the new names communicate the danger better.

avalanches, they pose different threats and can be of relevance in avalanche danger assessment. Avalanches can be divided roughly into three types; slab, loose, and glide avalanches. Their characteristics differ in terms of how fast the snow stabilises, possibility of remote triggering, typical release zone steepness, release characteristics and destructive force related to size and density (EAWS, 2019).

3.1.14. Summary snow and avalanche factors

To summarise, all the DMFs use factors 1–5 (signs of instability, loading of new snow, wind or rain within the last 48 h, critical warming, signs of slab avalanches within the last 48 h) to some degree. However, not all DMFs use presence of persistent or deep persistent slab problems, how snow feels when moving on skis, unusual, infrequently travelled route, pillows of wind drifted snow or cornices. What distinguishes factor 1–5 from the other factors is that they generally are easier to observe and interpret, i.e. are direct evidence with a high level of certainty, and competence required to evaluate them is moderate.

However, experts use a range of factors but, somewhat surprisingly, not all experts use signs of instability (Table 3).

3.2. Snowpack evaluation and stability test factors

Category B consists of two sub categories; B1) *snowpack evaluation* and B2) *stability tests*. In situations with poor snowpack stability, nature provides us with rather obvious signs. These warning signs, such as recent avalanches, shooting cracks and “whumpfs”, indicate an unstable snowpack and are typically associated with danger level 3 - considerable or higher. The more stable the snowpack, the greater the load it can support before it fails. In these situations, instability can be less obvious and more indirect factors have to be evaluated. A snowpack can have a favourable buildup, e.g. no slab on a weak layer, only loose snow. In these situations, the snowpack is considered stable and no avalanche danger exists.

Factors in subcategory B1 *snowpack evaluation* belong to both class 2 data and class 1 data (MCCLung and Schaeerer, 2006a). In order to evaluate snow cover and be able to assess the current avalanche situation, knowledge of snow classification is required. Due to the nature of these factors, there is uncertainty and a careful interpretation required.

The descriptions of the factors in this group is based on the threshold sum approach (Jamieson and Schweizer, 2005b; Schweizer and Jamieson, 2002) and a description of the practical application of the SSD (Kronthaler and Zenke, 2006).

3.2.1. Factor 1: hardness of the overlaying snow

By overlaying snow, we mean the snow above a potential weak layer. The hardness of the overlaying snow is one of the factors determining what will affect the weak layer and possibly initiate a fracture that could lead to an avalanche release (Kronthaler, 2003; Kronthaler and Zenke, 2006). Additional load by backcountry travellers, precipitation type, intensity and amount, solar radiation and temperature are all criteria to be taken into consideration when assessing the importance of the hardness. It is also of importance for potential avalanche size.

3.2.2. Factor 2: weak layer distance from snow surface

This factor is evaluated in combination with the factor hardness of overlaying snow, and affects sensitivity to trigger and potential size of an avalanche. The effect of the additional load of a backcountry recreationalist, additional wind loading or precipitation and possible additional weakening by rain or high temperatures on the weak layer are all of importance. There are countless possible combinations of the distance from surface and the hardness of overlying snow, and this has to be assessed for each individual situation. The influence of skiers on a weak layer decreases with increasing depth, i.e. weak layers deeper than 80 cm from snow surface are hardly affected by skiers (Schweizer

and Camponovo, 2001). However, additional stress is dependent on riding style, e.g. falls. Dependent on terrain, the depth of snow, and thus the depth of the weak layer, can vary considerably over short distances. This makes the estimation of depth very difficult in practice, as changes in topography, wind-deposited snow depths, inclination etc. may have a strong effect on the importance of the depth to the weak layer.

3.2.3. Factor 3–6: weak layer properties

We present four factors in the same heading because they are evaluated in combination. The four factors are: grain size; grain type; thickness and difference in hardness. One factor, difference in hardness > 1 between layers, is not part of any DMF, was not asked for by any of the experts, and was not included in the survey. However, it is part of the threshold sum approach and hence included in this section.

When analysing the properties of a weak layer grain type, grain size and layer hardness is of importance (Jamieson and Schweizer, 2005a). Grain size > 1.25 mm is regarded as unfavourable. Layers consisting primarily of surface hoar, facets and depth hoar and layer hardness softer than 1F (one finger) are regarded as unfavourable. Also of interest are the properties of the boundaries or interfaces between layers. A differences in grain size > 0.5 mm and a difference in hardness > 1 are regarded as unfavourable. A weak layer thickness of < 3 cm is also considered unfavourable (Kronthaler et al., 2013). Grain size, type and hardness are dependent on the processes affecting snow metamorphosis. By understanding these processes, one can estimate the distribution of a weak layer.

The analysis of weak layer properties can be done systematically and is then called: Threshold sum or yellow flags (Schweizer and Jamieson, 2007). Only minor differences separate the Threshold sum from the analysis of weak layer properties used in the SSD. The analysis of weak layer properties is often combined with stability tests by experts.

3.2.4. Factor 7: fracture character

This factor is evaluated from stability tests. It is important to obtain a better understanding of snow stability / instability. Fracture character / shear quality is significantly less spatially variable than stability test results. This factor is regarded as class 1 data in relation to predicting avalanches. Fracture character is divided into 5 classes, with a corresponding description and code for each class (e.g. Sudden Planar, code SP, description: Planar fracture suddenly crosses column in one loading step and the block slides easily on the weak layer) (van Herwijnen and Jamieson, 2004). It is also common to use the three-class Shear Quality score (Q1, Q2, Q3) which is an expression of how even or uneven the shear surface is (e.g. Q1 clean, planar, smooth and fast shear surface; weak layer may collapse during failure) (MCClung and Schaerer, 2006a). The SSD uses the terms Smooth or Stepped fracture (Glatter oder Gestufter Bruch) (Kronthaler, 2003; Kronthaler et al., 2013).

3.2.5. Factor 8: test score from stability tests

The tests differ in descriptive terms, coding and description of load at failure because they are designed to test different snowpack properties (see below), and have different strengths and weaknesses. For example the Rutschblock test uses 7 load levels, and failure with load levels 1, 2 and 3 stability is rated poor. A detailed description and stability interpretations on the basis of test scores can be found in (MCClung and Schaerer, 2006a; Kronthaler, 2014).

3.2.6. Factor 9: combination of different elements

Evaluating the different snowpack factors in combination constitutes the actual diagnosis in the SSD. This component is thus an assessment of the various factors of a snowpack evaluation (factor 1–8) and the interaction between them. Individually, the different factors do not necessarily imply any instability or danger. What matters is the interaction and properties of the different factors or elements. For

example: consider the surface of a stable snowpack with a layer of surface hoar with unfavourable properties (2.5 cm thick layer, 10 mm crystals, fist hardness). This layer is then covered by a 30 cm layer of unbounded, dry, loose, new snow. Even if a weak layer exists, the surface hoar layer, there is no slab avalanche problem because the slab is missing.

3.2.7. Summary B1: snowpack evaluation

Snowpack evaluation requires knowledge, detailed observation, a careful weighing of factors and the interaction between factors. The more distinct the unfavourable snow layer properties and interfaces are, the more unstable is the snowpack. As important and valuable the threshold sum approach may seem, it is accurate only about 60–75% of the time and should be interpreted alongside other information including snowpack distribution over terrain, according to the method developers (Schweizer and Jamieson, 2007). The SSD uses many of the same factors as the threshold sum approach when evaluating snow layer properties, and snowpack evaluation is essential. In a comprehensive real-life test involving 190 test slopes, the accuracy rate was very high (99.34% for stable slopes) (Kronthaler et al., 2013).

As Table 4 shows, the reduction methods ASM, SoG and RM, have no or very little focus on snowpack evaluation. SC and GRM have some focus on this in their accompanying literature (Harvey et al., 2018; Engler et al., 2001), but without offering any structure on how to systemise and interpret these factors. The NT focuses only on the presence of a weak layer, whereas the stability test scores and fracture character are included in the A2.0.

Overall, the DMFs assess snowpack differently. There is not a single factor that is common to all DMFs.

3.2.8. Factor 10: B2, Stability tests

Together with snowpack evaluations, stability tests are an important part of avalanche forecasting (MCClung and Schaerer, 2006a). Observing clear signs of instability implies that travel on similar slopes with similar conditions will be high risk. When instability is less obvious, tests that make the user aware of unstable conditions are highly valuable. Quite often, the spatial distribution of a specific instability is more limited in lower danger situations, i.e. level 1-low or 2-moderate situations, than at higher danger levels. In order to expose these instabilities, it may be necessary to perform several tests to track the instability.

Evaluations and tests are also used to directly assess avalanche danger in the field. We included tests that either are part of a decision-making framework, or frequently involved in evaluation of instability: the Rutschblock Test (RB), Compression test (CT), Extended column test (ECT) and the Small Block Test (SBT). Detailed description of the tests can be found in e.g. (Jamieson, 1999; Kronthaler, 2014; Schweizer, 2002; Simenhois and Birkeland, 2009). We describe also two informal tests; 1) ski cut and 2) hand shear.

3.2.8.1. Small block test (SBT). The SBT is an important factor in snowpack evaluation and decision-making using the SSD. The test is not a stability test in a traditional sense. However, it tests the initial fracture with the amount of force applied and the type fracture with the propagation potential. Other tests consider load levels and scores or descriptive terms (MCClung and Schaerer, 2006a), whereas the SBT core target is to identify potential weak layers within a snowpack and then evaluate its properties. SBT distinguishes only between light, moderate and hard lateral tapping and smooth, rough, and “stepped” fractures (Kronthaler et al., 2013). The SBT is the only test that uses lateral loading/tapping. In a recent study (Kronthaler et al., 2018) significantly more energy had to be applied to initiate a fracture when using vertical load compared with lateral load. In addition, applying vertical load revealed just over half of the weak layers compared to the SBT. Also, the dispersion of stability values was significantly larger using vertical load. The authors concluded that the SBT can be used to

make more reliable statements about the properties of the weak layers. However, they also stressed that one test is insufficient in slope specific decision-making independent of lateral or vertical tapping. Therefore they recommend performing several tests and analyses of the weak layer using the threshold sum method or the analysis structure used in SSD.

3.2.8.2. Rutschblock test (RB). An isolated block of snow, preferably on a 30° inclined slope, is loaded by a person in several stages (MCClung and Schaerer, 2006a) and load levels for Rutschblock failure are interpreted in several stages from having poor to good stability. However, it is challenging to find a safe spot to perform the test.

3.2.8.3. Compression test (CT). The test can be used to identify weak layers in the snowpack, and uses loading steps to initiate failure in a weak layer (MCClung and Schaerer, 2006a). The loading is applied vertically on an isolated column measuring 30x30cm. The descriptive terms for failure range from very easy to no failure. Interpretation of results should include shear quality.

3.2.8.4. Extended column test (ECT). This test gives information on fracture initiation and fracture propagation (Simenhois and Birkeland, 2007). Like the CT, vertical loading is applied in different steps. The isolated column measures 30x90cm. Descriptive terms for propagation range from no fracture to fracture propagates during isolation.

3.2.8.5. Propagation saw test (PST). This test indicates how easily a fracture propagates in a chosen weak layer in the snowpack. A column of 30 cm width and 100 cm horizontal length in slope direction is isolated. Vertically it has to be isolated deep enough to include the weak layer. If the weak layer is deeper than 100 cm the length of the column should match the depth of the weak layer. Sawing with the blunt end of a snow saw in the weak layer is done until a fracture propagates through the whole column.

3.2.8.6. Ski cut. Ski cut or ski cutting is not a formal test, has no stepwise loading levels or recording standards. It can be used to test slope stability using skis primarily on smaller slopes. Pro-skiers and expert riders sometimes perform ski cut at the very top of a run in order to release a potential avalanche before exposure to the entire slope. The effectiveness is condition-dependent and not risk-free.

3.2.8.7. Hand shear test. If a weak layer has been identified, and if it is high in the snowpack then it can be tracked using an informal test, the hand shear test. It is performed by isolating the overlaying snow by hand. Next, one evaluates the interface between the weak layer and the isolated column and the weak layer properties. The hand shear test has no defined block size, nor does it imply any stepwise loading levels or recording standards. The test can also be used to determine if the overlaying snow is loose or bonded.

3.2.8.8. Summary stability tests. In the SSD, the key component is finding the most prominent weak layer and testing the weak layer - slab combination using the SBT. Results are interpreted considering the processes that lead to the weak layer slab combination observed. Based on this, the user can assess release probability for the investigated slope. During a comprehensive field campaign, the transferability of the danger assessment to neighboring slopes was tested. Results showed that in situations with low release probability the variability of the prominent weak layer was higher than for situations with high release probability (Kronthaler et al., 2013). Based on their investigation the authors conclude that snowpack evaluation, using the little block test and analysing snowpack and weak layer properties provide robust results in slope specific avalanche danger assessment.

For other DMFs, only the A2.0 and GRM mention stability tests in their accompanying literature (Harvey et al., 2018; Haegeli et al.,

2010), but offer no information or structure on how to interpret and use this information. In the ASM, stability would naturally fall under safety wall 1-danger assessment, but is instead presented in a separate chapter called depth knowledge and can therefore not be considered part of the framework (Brattlien, 2014).

The best tests for backcountry travellers will be those having the best balance between time consumption, risk in performing the test, ease of interpretation and reliability in identifying instability relevant for the user. All stability tests are point measurements that can provide high-quality information, but have limited value beyond the area where they are performed. Therefore one should always evaluate them in association with other factors (MCClung and Schaerer, 2006a).

3.3. Avalanche forecast factors

To provide the public with detailed information about the snowpack and current avalanche situation many countries have avalanche warning services publishing avalanche forecasts, also called bulletins (Engeset et al., 2018). Category C includes the factors used in the bulletins (also called warnings and forecasts).

In general avalanche forecasts have similar content and use an information pyramid, presenting the most important information, the *danger level*, first.

3.3.1. Factor 1: danger level

The danger level uses a five-stage scale, ranging from 1-low to 5-very high (5 is labeled extreme in North America). Each danger level is derived from a set of definitions, expressing the interaction between all evaluated factors. The European danger scale is a function of a) probability of avalanche release, b) distribution of hazardous sites and c) avalanche size. European forecasting services use the EAWS Matrix to determine the danger level.

As Table 5 shows, except for the NT and SSD, the danger level retrieved from an avalanche forecast is either a factor on par with other factors (AT and A2.0) or the most prominent factor and starting point in the decision-making process.

3.3.2. Factor 2: main message

Large amounts of data are analysed and the resulting forecast is the condensed presentation of this data. The *Main message*, is not integrated in the information pyramid, but is the forecaster's opportunity to communicate directly with the reader in order to inform and point at key aspects of the avalanche situation in a concise way, relating the message, i.e. "this is what you have to be aware of". If there are changes in the avalanche problem, important new observations, or significant changes in weather, the main message will include this information.

3.3.3. Factor 3: avalanche prone locations (aspect, elevation and specific terrain features)

Avalanche prone locations are areas where the danger is particularly significant. In the forecast, these areas are described using graphics and text. There are two ways to incorporate this factor into the avalanche assessment; A) as a physical factor, i.e. that the location is of importance for snow metamorphism and snow stability such as effects of temperature dependence on altitude and effects of solar radiation dependence on aspect, or B) as a statistical factor, i.e. taking into account where accidents tend to occur. For example avalanche fatality statistics from the Alps show that a majority of accidents are located in the northern sector. How the DMFs use this factor varies.

3.3.4. Factor 4: avalanche problem

When writing an avalanche forecast, the forecaster can choose between five (Europe, EAWS, 2019) or eight (North America, Statham et al., 2006) different *avalanche problems*. A forecast can contain up to three different avalanche problems. The avalanche problem is third in the information pyramid, but to the experts (Landrø et al., 2019) it is

the most important factor in the forecast. Avalanche problems are a good starting point for an analytical danger assessment. Avalanche problems directly influence terrain choice, what type of observations are relevant, procedural choices, and they determine the degree of uncertainty in the current situation.

3.3.5. Factor 5: mountain weather

Weather affects the snowpack and thus the avalanche danger. *Mountain weather* gives information on previous, current and future weather and its effect on avalanche danger. This factor can be of importance for the type of avalanche problem, weak layer formation and development in addition to more general information on what conditions (wind, temperature, precipitation) and visibility one can expect.

3.3.6. Factor 6: snowpack information

In the *snowpack information* part of a forecast, a general description covering both the layering of the snow and the stability is given. This allows understanding of the processes causing the current snowpack, the further development of the snowpack, possible destabilisation, and facilitates managing the avalanche problem.

3.3.7. Factor 7: travel and terrain advice

This factor is especially aimed at snow sports enthusiasts and is in addition to the recommendations defined in the avalanche danger scale. Recommendations are often linked to how to handle different avalanche problems. Experts consider this factor mainly during planning and route-selection. It is of limited use, probably due to the advice being too general or obvious for the expert user.

3.3.8. Summary avalanche forecast

Except for the NT and SSD, the danger level retrieved from an avalanche forecast, is either a factor on par with other factors (AT and A2.0) or the most prominent factor and starting point in the DMFs.

However, reliance on the danger level has been criticised for several reasons:

- a. The danger level is not suited for small-area or slope specific descriptions, nor was it developed for that purpose (Nairz, 2010);
- b. There is no objective definition of how to determine the danger level, neither in the forecast nor in the field;
- c. In reality, danger level changes continuously, not stepwise as in the scale. The steps imply distinct danger level bands;
- d. (Lack of) uniformity of the forecast (Müller et al., 2016);
- e. Uncertainty related to prediction (forecast) and systematic verification procedures regarding the danger level (Schweizer, 2010; Schweizer et al., 2003a; Techel et al., 2016b);
- f. The risk calculation (including the danger level) ignores the total number of people travelling in the backcountry (McCammon and Hägeli, 2005; Kronthaler, 2001);
- g. Accident-based risk calculations do not take into account all the cases where an expert has chosen not to enter a specific slope on the basis of his or her avalanche danger assessment. In a calculation, this should have counted as an event;
- h. The avalanche problem has no *direct* influence on determining the danger level (e.g. calculations by (Techel and Winkler, 2015) show that the relative risk is 50% higher at the same danger level in situations with persistent weak layers than with other avalanche problems).

3.4. Group and group management factors

Category D consists of two related subcategories; *Group factors* and *group management factors*. *Group factors* can be regarded as a physical factor (weight), statistical factor (accidents), human factors (heuristic traps). How these factors are regarded and used in the DMFs differ. In this category, the skills, level of fitness, safety equipment and training

in avalanche rescue of the group are assessed.

Group management factors are concrete measures concerning how a group travels in avalanche terrain to minimize risk. On the one hand, these factors are about exposing as few as possible to avalanche risk at the same time, and on the other hand they are about minimising the extra load backcountry recreationalists exhort on the snowpack. These factors are standard travel measures and are applied independently of the DMFs. However, they are an integrated part of some DMFs.

3.4.1. Factor 1: group size

This factor classifies groups into small (2–4 people), large and very large (Munter, 1997). The NT defines groups > 5 people as negative. Note, that there is no universal definition of large and very large groups. Regarding different heuristic traps, such as the Expert Halo, Social Facilitation and Acceptance (McCammon, 2004), organisation and communication in the group are probably more important than group size.

3.4.2. Factor 2 and 3: group skills and fitness level

Low technical skiing skills increase the likelihood of falling, resulting in high, abrupt additional load on the snowpack, increasing the likelihood of an avalanche release. Skiing skill is also important for keeping the optimal planned line and for stopping at safe spots. Low levels of fitness also increase the physical demand on the skiers leaving less surplus energy for avalanche danger assessments and route selection. There is also extensive evidence suggesting that high levels of physical activity decrease a person's cognitive abilities to make sound decisions (Hetland et al., 2018).

3.4.3. Factor 4 and 5: avalanche rescue skills and safety equipment

These factors belong together and assess whether group members have the necessary safety equipment (transceiver, shovel, and probe) and the skills to rescue a companion (Falk et al., 1994). Avalanche rescue skills essential for efficient companion rescue, thus increasing survival chances in case of an avalanche burial. Using rescue strategies, teaching methods and rescue equipment optimized for novices, companion rescue can be performed very efficient and successful (Genswein, 2008 #154) (Genswein, 2008 #616), even in complex situations with multiple burials. The three main tools: transceiver, shovel and probe, must be used in combination to function optimally (Stumpert, 2002).

3.4.4. Factor 6–11: standard travel measures, group management techniques

Standard travel measures are the steps to handle avalanche risk. Different DMFs provide variants of factors such as: a) One-at-a-time exposed, b) safety distance when ascending, c) one-at-a-time 35°, d) 30 m distance, e) safety distance 10 m from 30° onwards, f) skiing with distance. These were presented as different items in the survey but have been collapsed into one factor in this analysis. This factor is primarily a risk reduction measure to limit additional loading on the snowpack. It is connected to the definitions in the European Avalanche Danger Scale (EAWS, 2019). In the description of likelihood of triggering, descriptions such as “Triggering is possible, even from low additional loads (danger level 3-considerable)” are used. Low is defined as: individual skier / snowboarder, riding softly, not falling; snowshoer; group with good spacing (minimum 10 m) keeping distances. High load is defined as: two or more skiers / snowboarders etc. without good spacing (or without intervals).

Secondly it is a measure that can limit the number of people caught in an avalanche release. The different variations of the factor, regarding recommendations at different inclination are based on avalanche accident statistics and related to risk calculations. Applying this management strategy in large groups and on long runs costs time, but the benefits outweigh the disadvantages.

3.4.5. Factor 12: clear direction

This is a risk reduction measure optimising line selection in relation to skiing the best snow possible, avoiding terrain traps, avoiding trigger points and especially exposed areas. Clear directions that are heard and understood by the group are an essential factor to manoeuvre groups in avalanche terrain.

3.4.6. Factor 13: Stopping at safe spots

This is a risk reduction measure that ensures safety in case of an avalanche release triggered by someone else in the group.

3.4.7. Summary group factors and group management

All DMFs have recommendations to minimize the risk of getting caught in an avalanche. The primary focus is to avoid avalanche release, not to provide detailed group management strategies in avalanche terrain.

Some DMFs include group management techniques that are mainly slope specific. A few of the DMFs from the Alps, such as SoG and SC, use what is called *Einzugsgebiet* meaning assessment area and it describes the amount of terrain that should be taken into consideration. The assessment area is derived from the danger level. For example, at danger level 2-moderate, track surroundings or areas within 20 m should be considered, and at danger level 3-considerable the entire slope should be considered. This approach may be insufficient when the avalanche problem is associated with a risk of remote triggering (i.e. persistent weak layers), natural releases at lower danger levels and infrequent but long avalanche runouts at lower danger levels. The assessment area concept and the high and low additional load definitions in the EAWS contribute to the different risk reduction measures.

As Table 6 shows, as many as six group factors are used by nearly all experts (> 90%) and four of these are considered decisive by two of more out of three experts. In other words group size, technical skills, physical shape and avalanche rescue training are important.

3.5. Terrain factors

Avalanche hazard is based on evaluating the interaction of four variables – snowpack, weather, person and terrain. *Terrain* is the foundation for avalanches and without an inclination of minimum 30°, avalanches will usually not occur. When assessing avalanche danger, terrain factors can be used as physical factors (e.g. inclination) or a statistical factor (avalanche accidents). Category E includes different factors used to describe the terrain.

Inclination plays an important role in all three processes relevant for dry slab triggering (Schweizer and Camponovo, 2001; Heierli et al., 2008; Heierli et al., 2011; Schweizer et al., 2003b):

- Fracture initiation – likelihood increases with steepness
- Fracture propagation – likelihood increases with steepness (but dependent on several factors)
- Slide - dry snow slides at inclinations steeper than about 30°

However, avalanche statistics show that most accidents happen on slopes between 35° and 40° (measured at the steepest point), independent of avalanche danger level (Harvey et al., 2012).

Apart from inclination, commonly used terrain factors include terrain traps, curvature/convexity, avalanche paths, forest, safe spots, etc.

3.5.1. Factor 1: 5° intervals from 30°

This factor originates from a statistical/probabilistic approach to avalanche danger assessment and decision-making and measures inclination in 5° intervals. Frameworks derived from the RM use it in combination with danger level to reduce risk (Munter, 1997). Inclination belongs to what Munter calls First Class Reduction Factors. For example, at danger level 3-considerable, if the steepest part of the slope is 35°-39° (< 40°) this gives a First class reduction factor with a score of

2.

Similarly, A2.0 differentiates between slopes 30°-35° and slopes steeper than 35° and gives them a score of respectively +1 and +2 in the terrain characteristics score card.

3.5.2. Factor 2: danger level/slope inclination

This factor corresponds to factor 1 in Category C and factor 1 in Category E.

3.5.3. Factor 3: discriminating between avalanche terrain and non-avalanche terrain

Here, users need to distinguish only between avalanche terrain (terrain steeper than 30° and runout zones) and non-avalanche terrain. Because the total number of people in avalanche terrain (including exact inclination) is unknown, as well as the exposition and danger level it is not possible to calculate an individual's risk. Instead, the inclination at which there are no accidents should be found, up to 40° at danger level 1 and up to 30° at danger levels 2, 3 and 4 (Kronthaler, 2001). This does not take into account groups that have turned around in terrain steeper than 40° at danger level 1-low, due to a local danger assessment.

3.5.4. Factor 4: avalanche terrain exposure scale (ATES)

ATES is a Canadian initiative to classify terrain into three different classes: simple, challenging and complex. The three classes are determined in a technical model that describes exposure to different terrain elements (e.g. inclination, forest density, terrain traps, avalanche frequency). In addition to the technical model, there is a public communication model targeted at a less skilled audience (Statham et al., 2006). ATES is well suited to teach avalanche terrain fundamentals and basic route finding, and can help balance terrain choice, conditions and competence. Guide books or maps showing terrain or routes that have been classified using ATES assist backcountry travellers new to an area to identify terrain that matches their competence and the current avalanche conditions.

3.5.5. Factor 5: use of favourable terrain formations

Use of favourable terrain formations refers to terrain where the impact of the additional load is limited such as thicker snowpack, avoiding high stress areas such as convexities (tension) and concavities (compression), and where the consequences of an avalanche are thought to be less serious as where there is a smooth runout without obstacles and terrain traps.

3.5.6. Factor 6: avoiding terrain traps

This factor has nothing to do with avalanche release, but refers to the consequences of an avalanche. Gullies, cliffs, trees and crevasses are examples of such. Flats at the bottom of steep slopes that may accumulate a deep avalanche deposit on top of an avalanche victim, are another example.

3.5.7. Factor 7: forest density

This factor can be both a positive and a negative factor depending on tree species and forest density. Trees will have an effect on snowpack layering (i.e. temperature, wind, incoming and outgoing radiation, interception of snowfall), can have an anchoring effect (dependent on slab stiffness) reducing avalanche likelihood, or increase the likelihood when their effect is weakening the snowpack (i.e. facets and depth hoar development). When an avalanche releases in or flows into forested terrain, the consequences increase dramatically.

3.5.8. Factor 8: convex or unsupported slopes

Convex and unsupported slopes are terrain features that have an increased likelihood of avalanche release, unless the wind has removed potential weak layers. Convexities add tension to the snowpack and are likely trigger points given additional load or weakened bonds. On

unsupported slopes the slab lacks the additional support of the lower lying snow and the concave area. This is especially true for small and medium sized slopes, where forces acting on the slab (shear and compression) play an important role.

3.5.9. Factor 9: avoiding known avalanche paths

This factor originates from avalanche accident statistics. Terrain is obviously steep enough for an avalanche or acts as a runout-zone. Avalanche paths indicate a certain return frequency. In the ATES technical model, Avalanche frequency (events:years) is an important factor. In sparsely populated areas and areas without forests clearly indicating avalanche paths (i.e. sparse birch forest) it can be hard to determine avalanche frequency.

3.5.10. Factor 10: avoiding exposed routes without protected areas

This factor is not related to avalanche release, but to consequence. By exposed routes, we understand exposure to avalanche prone slopes. The use of protected areas (safe spots) is a means to reduce risk (see category D). Safe spots are used to limit the number of people exposed to risk at the same time. Especially in larger runs and complex / convoluted terrain this is a commonly used group management technique.

3.5.11. Summary terrain factors

Terrain as a factor in its entirety is important to all DMFs but usage varies. In some DMFs it is a one-dimensional physical factor, inclination. In other DMFs it is more complex, e.g. ATES. Terrain factors can be physical, necessary for or increasing the likelihood of avalanche release or a statistical factor stating the probability based on avalanche accident statistics. In DMFs derived from the RM inclination is a core factor, and together with danger level the avalanche risk is calculated. Inclination can be measured objectively, but there is still measurement error and uncertainty how “large” the steepest part has to be (Würtl, 2016):

- Maps and inclination maps masking the actual steepness by means of elevation lines. The elevation lines can have the same distance, but in reality the terrain can be much steeper in the range of up to 40 m than can be shown by the map.
- The maximum possible accuracy of measuring inclination on high quality maps is $4-5^\circ (\pm 2^\circ)$
- The ability to read inclination correctly requires training using a precise inclinometer to ensure accurate feedback on estimates during training
- A meaningful inclination estimate presupposes an optimal reference area. In practice, the steepest areas of a slope with a coherent size of approx. $20\text{ m} \times 20\text{ m}$ (400 m^2) is recommended. It can be relatively unproblematic to estimate inclination in smaller slopes, but poses serious potential risk in larger slopes.
- There are no standards regarding inclination measurements in avalanche accident investigations. These can be determined using maps, implying the sources of error described above. Whether inclination is measured on the snow surface, bed surface or ground is up to the expert assessment of the situation. In principle, only inclination of the snow surface should be considered as this is the only one that can be assessed by a backcountry recreationalist.

As Table 7 shows, only two terrain factors (terrain formations and traps) are used by nearly all experts (> 90%). However, discriminating avalanche terrain, convexities, avalanche paths and exposure also matters.

3.6. Expert use

We gathered data from experts on their use of the above reviewed factors. The full results are presented in Landrø et al. (2019). Tables 3–7 summarises the use and importance of the different factors. Factors can

be used but not deemed decisive, e.g. avoiding terrain traps. In category A, *signs of instability* and *loading of new snow* are used by 3 out of 4 experts. We refrain from speculating why not all experts use signs of instability but using an anonymous survey may elicit more honest answers than interviews.

Seven out of 10 factors in category B (snow evaluation) are used by > 2 out of 3 experts, but each individual factor is considered decisive by far fewer experts than category A factors. Given some overlap between the factors, and the categories, this is unsurprising, particularly since many experts also indicated the factors as relevant and situation-dependent.

In category C (avalanche forecast), all factors but travel advice are used by more than two out of three experts. However, these factors are not decisive for the majority. A possible explanation could be that avalanche forecasts are provided for areas (much) larger than 100 km^2 , and thus do not translate directly to making decisions on the slope-scale.

Six out of 13 factors in category D (group factors) are used by practically all experts, highlighting the importance of the human factor. Many of these factors were also considered decisive by at least half of the experts.

For category E (terrain), inclination is not a prominent factor. More than half of the experts rely on *discriminating avalanche terrain - not avalanche terrain*, *ATES*, *favourable terrain formations* and *avoiding terrain traps*.

3.7. Network analysis

The DMFs can also be analysed as networks in order to explore the relationships between them based on their factors. We coded whether the DMF uses the factor in its decision-making or not. By assigning binary coding as 0 = not included and 1 = factor included. When a factor can be regarded as part of a framework because it is included in accompanying literature, or is used indirectly (i.e. all snow and avalanche factors are indirectly a part of the SSD because they are a part of process thinking) we coded it as 0.5 instead of 1. The results are identical.

We used the network analysis function in jasp (jasp-stats.org). Unsurprisingly (see Fig. 2), the reduction method is a central node from which several DMFs derive. There is also a strong relationship between AT and A2.0. SSD and NT are not related to the reduction method family network. Thus, the analysis of the factors in the frameworks

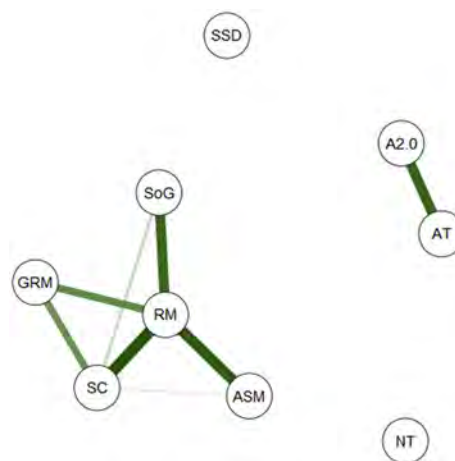


Fig. 2. Network analysis of the different DMFs based on shared factors. The line thickness and color strength indicate the positive correlation between the DMFs. Distance between the DMFs is of no importance. RM = Reduction Method, ASM = After Ski Method, SC = Snow-card, SoG = Stop or Go, NT = NivoTest, A2.0 = Avaluator 2.0, GRM = Graphical Reduction Method, SSD = Systematic Snow-cover Diagnosis, AT = ALPTRUTH.

resonates well with the historical emergence and philosophical background of the decision-making frameworks. More details on the network analysis can be found at <https://osf.io/2z95n/>

4. Discussion

In the current paper we present the first comparative and comprehensive overview of the factors described in the ten most commonly used DMFs and complemented by factors suggested by an avalanche expert advisory board. This resulted in 53 factors used in avalanche decision making. We grouped these factors into five different categories: A) snow and avalanche factors, B) snowpack evaluation and stability test, C) avalanche forecast, D) group factors and group management and E) terrain factors.

4.1. Comparing the frameworks

Our analysis shows that the frameworks differ in terms of number, type of factors and how they emphasise the factors they assess. The number of factors used by the different DMFs varies between 11 (AT) and 31 (GRM, SoG). There is no single factor that is shared by all DMFs, reflecting different decision approaches, varying in their degree of abductive reasoning. Frameworks belonging to the RM family resemble each other, varying only in minor details (Tables 3–7). The NT uses other factors than those in the RM family and also applies different calculations. AT and A2.0 share many of the same factors, but A2.0 gives the factors a score, uses more factors, includes analytic elements and is a considerably more comprehensive framework. The SSD is the only purely analytic framework. It differs from all the other frameworks on factors included and how these factors are assessed.

4.2. Snow and avalanche factors

The snow and avalanche category factors are the ones shared by most DMFs, especially those that are easiest to interpret, commonly called signs of instability. In some DMFs these factors are core factors on par with others, whereas in other DMFs, they are less important or used only indirectly (included in accompanying literature) and without offering any structure on how these factors should be systemised and interpreted. However, the developers of the frameworks appear to agree that factors belonging to this category are of importance and should be part of avalanche danger assessment and decision-making.

4.3. Snowpack evaluation and stability test factors

The largest difference amongst the DMFs is found in this category. The primarily probabilistic approaches (RM family and NT) do not include these factors, or at most use these factors indirectly. If included, they do not provide the user with any guidance or assessment structure. In contrast, the purely analytic SSD requires a thorough understanding of these factors.

4.4. Avalanche forecast factors

An avalanche forecast contains many factors. The main factor in the probabilistic DMFs (the RM family and NT) is the danger level, and secondary is the avalanche prone locations. Only the A2.0 uses avalanche problems as a factor. For the remaining factors there is only limited and indirect use, e.g. the RM, ASM, SC, SoG, GRM, NT and SSD indirectly include the existence of a slab problem. The danger level is a good indication of the situation one most likely will meet. However, the avalanche forecast is much more than danger level, and the avalanche problem and snowpack information have the potential of becoming important factors.

4.5. Group and group management factors

The human factor is absent in a range of DMFs, particularly in those of the RM family. A range of factors concerning group management are considered in the SoG and NT includes group factors such as assessing knowledge, skills and level of fitness. Given the inherent uncertainty and complexity in avalanche assessment it is striking that travel techniques like spacing out or stopping at safe spots are not included as a prominent measure in all DMFs. They are effective measures for handling residual risk and may determine the difference between an avalanche incident and fatal accident, as seen in their use by experts.

4.6. Terrain factors

As simplification, many DMFs have reduced terrain assessment to a measure of inclination. Even though inclination may be the most objective factor that can be measured, the complexity should not be reduced to one single factor. For example, terrain traps may increase the consequences of even small avalanches. Furthermore, measuring slope angle accurately in snow-covered terrain can be very challenging. Choosing terrain wisely according to the given condition may be one of the most important measures in avalanche decision-making.

4.7. Consequences

There are differences in the number, type and importance of factors amongst existing decision-making frameworks for avalanche terrain. The consequences of these differences are:

- Different DMFs can give conflicting results when it comes to go / no-go decisions
- Different DMFs pose different demands on user knowledge and competence
- DMFs differ in ease of use
- DMFs differ in level of residual risk they accept
- DMFs differ in the amount of terrain regarded as accessible given current conditions.

Our analysis shows that the factors included in the different frameworks range from simple to complex as well as simplifications of complex factors. Some factors are used from a statistical perspective in some frameworks, whereas others assess the same factors as a physical factor. The descriptions of each factor lay the foundation for a future assessment of their ease of use, importance, reliability and significance. Even use of the factor regarded as most objective, inclination, comes with challenges. This confirms that avalanche danger assessment involves reducible and irreducible uncertainty, and that there can never be absolutely certainty in assessing the avalanche risk.

4.8. Limitations

The presented frameworks undergo revisions, and our analysis is based on the latest versions we were aware of at the time of this analysis.

We did not review the decision-making processes of each DMF in detail, as our focus was on collecting the various factors and their use by experts. The natural next step is an analysis of the decision-making process itself.

5. Conclusion

A correct assessment of avalanche danger is crucial in order to avoid accidents. Researchers and avalanche experts have developed a range of avalanche decision-making frameworks to support decision-making in avalanche terrain and reduce fatalities. These frameworks rely on and assess different factors to provide a go or no go decision. We identified

44 factors included in the checklists, cards or described in the accompanying literature belonging to the different frameworks. Nine other factors were added based on feedback from pretesting our survey, resulting in 53 factors.

The frameworks were developed to make informed and ultimately safe decisions but the disagreement amongst the frameworks and factors used by experts warrant reconsideration and revisions. By collecting and reviewing the relevant factors in avalanche decision-making we provide the foundation to improve the decision process.

Declaration of Competing Interest

All authors declare that they do not have any conflict of interest.

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Avalanche decision-making frameworks: Factors and methods used by experts



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ABSTRACT

The snowy mountains of the world attract more and more backcountry recreationalists. Besides beauty and joy, traveling in avalanche terrain can involve risk of injury and even death. A correct assessment of avalanche danger and following a correct decision is crucial. This requires a thorough evaluation of a range of factors. To aid these decisions several decision-making frameworks (DMF) have been put forward. However, actual use of these frameworks and their underlying factors can be questioned. We asked 100 experts about their familiarity and usage of the DMFs and their underlying factors. We found a large discrepancy between familiarity with and actual use of the most commonly used DMFs. In contrast to most frameworks that have a probabilistic approach, experts primarily use an analytical one. We also found that experts use more factors and emphasize other factors than most DMFs do. Indeed, the factors the experts use do not match any of the DMFs well, with the agreement ranging from 56% to 73%. Factors seen as core in many frameworks, such as the combination of danger level and slope inclination, are by a large margin the least used of all the terrain factors among the experts. We found a void between the existing frameworks and how – and on what basis – experts make their decisions. Our findings raise a fundamental question: How, when and where do the transition from novice to expert occur? Future initiatives to revise or develop new decision-making frameworks should take into account what experts use.

1. Introduction

Avalanches pose a major threat to recreational travelers in mountainous regions of the world. The fatality rate per year averages about 100+ in Europe with another 40 in North America (CAIC; Boyd et al., 2009; Techel et al., 2016). In 9 out of 10 fatal accidents among recreational backcountry travelers the victim or somebody in the party triggered the avalanche (Schweizer and Lüttsch, 2000; McClung and Schaerer, 2006). A correct assessment of local avalanche danger is therefore lifesaving. The avalanche danger can never be reduced to zero in avalanche terrain, however a thorough evaluation of a range of factors can reduce the danger considerably, and contribute to safe decisions (McCammon, 2000; Haegeli, 2010). The problem is, that humans are susceptible to a range of biases and thinking fallacies that may hamper arriving at a safe decision (Kahneman, 2011; Gigerenzer, 2014). Another problem is the uncertainty of the information at hand and the insufficient understanding of the relevant processes (McClung and Schaerer, 2006; Statham et al., 2018). As a response to the challenge of evaluating avalanche danger, avalanche experts and scientists have developed a range of decision-making frameworks (DMFs) to aid

the decision-making process.

In 2005 the Canadian Avalanche Association (CAA) published a comprehensive report describing and evaluating four of the existing European DMFs for recreational backcountry travelers (McCammon and Hägeli, 2005). The goal was to evaluate the utility of these frameworks for their use in North American avalanche terrain. The performance of each framework was determined by applying it to a database of 751 avalanche accidents. Utility for the different frameworks was determined by three factors: preventive value, mobility, and ease-of-use. The study showed that not all of the existing frameworks work equally well in every situation. Most frameworks perform poorly at low and moderate avalanche danger. They are sensitive to different climate zones that can have an effect on typical avalanche problems in a region. Like for example that persistent weak layers tend to be more frequent in continental climate zones than in maritime climate zones. The CAA study also points out that many users may choose not to use the methods, as the frameworks cast severe limitations on how much terrain is available for skiing. The authors also found that simpler frameworks appeared to be superior to more complex ones, a fact that is also well documented for other complex decisions (Gigerenzer, 2014).

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A study from the Alps, where the development of these frameworks has the longest history, found a limited use of decision aids by the intended target group, the backcountry recreationalist (Mersch et al., 2007). A more recent study on group dynamics and decision-making, showed no formal use of published decision aids among the interviewed groups (Zweifel and Haegeli, 2014). Similarly, other studies have found that users did not correctly integrate the available information in the decision-making process or applied inappropriate decision-making strategies (McClung, 2002; McCammon and Haegeli, 2004). Further, in our experience, avalanche experts seem to have a different approach to decision making. This raises concerns about the utility of the DMFs.

The primary target group of existing frameworks are amateur backcountry recreationists. One argument in favor of developing DMFs is that most backcountry recreationists spend too little time in avalanche terrain to develop a meaningful experienced-based approach. To cater to this target audience, most existing frameworks work with simplifications to meet the limited experience and knowledge of the user. This, though, risks losing the distinction between how accurate a factor can be assessed and how reliable the factor is in predicting an avalanche (Pfuhl et al., 2011). Furthermore, simplifications may lead users who have gained some personal experience to deviate from the original rules and structure set out by the frameworks.

This raises two interesting questions: Do the experts, the ones with most exposure and experiences with decision-making in avalanche terrain, base their decisions on the same factors as used in the frameworks? Do existing frameworks provide a structure that users can use at different levels of competence? Here, we will address these questions by investigating the use of DMFs and their factors among experts employing a quantitative survey.

Given the complexity of the material we have collected during this study, we have chosen to present the results in two accompanying articles. In this article we report the experts' knowledge and use of the DMFs and their underlying factors based on data collected by a survey of experts using an online questionnaire. The accompanying article (Landrø et al., 2019) presents the most commonly used DMFs and provides a detailed presentation of the factors used in these avalanche DMFs as well as the factors used by. We recommend reading the accompanying article as an introduction to the article at hand.

1.1. Decision-making frameworks used in the survey

We focus on ten widely used decision-making frameworks. These are; 3×3 (Munter, 1997), the Reduction Method (professional) (Munter, 1997; Munter, 2009a), Stop or Go (Larcher, 1999), Snow-card (Engler, 2001), the Graphic Reduction Method (Harvey, 2012), the After Ski Method (Brattlien, 2014), NivoTest (Bolognesi, 2000), ALP-TRUTH (McCammon, 2006), the Avaluator 2.0 (Haegeli, 2010), and the Systematic Snow-cover Diagnosis (Kronthaler, 2013).

An overview of the frameworks is presented in Table 1. Many of the frameworks are used in combination with the 3×3 by Munter or similar three step approaches. The 3×3 is not seen as a DMF in itself,

Table 1

Decision-making frameworks used in the survey with description of decision-style (terminology from Munter, 2009b), and number of underlying factors. The 3×3 filter method is not included as it is an approach to structure the decision process.

Framework	Abbrev.	Region	Decision process	# Factors	Reference
Reduction Method	RM	Alps	Probabilistic	15	Munter (2009a)
After Ski Method	ASM	Norway	Probabilistic	18	Brattlien, 2014
Snow-card	SC	Alps	Probabilistic	29	Engler, 2001
Stop-and-Go	SoG	Alps	Probabilistic	31	Larcher, 1999
Graphical Reduction Method	GRM	Alps	Probabilistic	31	Harvey et al., 2012
NivoTest	NT	Alps	Probabilistic,	27	Bolognesi, 2000
Avaluator 2.0	A2.0	US / CA	Probabilistic and analytical	27	Haegeli, 2010
ALPTRUTH	AT	Alps	Probabilistic	11	McCammon, 2006
Systematic Snow cover Diagnosis	SSD	Alps	Analytical	27	Kronthaler et al., 2013

but rather an overarching way of structuring the decision process into three different stages. Even if one does not use the 3×3 by Munter, it is common to divide an outing into different stages. The stages can be seen as a decision-making process that starts with trip planning, continues with route selection and culminates with slope specific decision-making. The idea is that it helps to make decisions and gives several possibilities to make changes to current plans given new information, thereby reducing the risk of an avalanche. According to Munter, only by using both the 3×3 and the RM, one achieves the intended level of risk (reduction) Munter was aiming for (Munter, 2009b).

In addition to the existing DMFs we asked the experts questions about the use of intuition in expert decision-making. We defined intuition in the survey as gut feeling, decisions that are difficult to explain, and/or decisions based on long-term experience. It is not unknown that different experts rely and sometimes base their decisions on intuition (Mersch and Behr, 2009; Mersch and Kühberger, 2009). Therefore, we included a broad definition of intuition as an additional or alternative decision-making “framework” in the survey (Fig. 1, Table 3).

The frameworks fall into two general categories: probabilistic and analytical. Probabilistic approaches calculate risk based on combinations of probabilities derived from avalanche statistics. The Reduction Method and DMFs deriving from this method use such a probabilistic approach. In contrast, DMFs such as the Systematic Snow over Diagnosis use an analytic approach. In such a DMF one evaluates the different factors to decide whether to ski a specific slope or not, requiring knowledge and the ability to see how the different factors interact.

1.2. Underlying factors in the avalanche decision-making frameworks

In all these frameworks the decisions are based on an assessment of a range of different factors. We refer to factors that constitute the basis of a DMF as direct factors. These are typically printed on a plastic-coated card that can be taken on a trip. Additional factors, that are presented in accompanying literature (i.e. a leaflet), and therefore can be regarded as part of a DMF, are referred to as indirect factors. Here, the assigned number of factors is the sum of both direct and indirect factors, see Landrø et al., 2019 for more details and a full review of the factors. Briefly, we identified 53 different factors that can be grouped into five different categories (Table 2). Some of these 53 factors are used by all DMFs, a few are not part of any DMF but mentioned by avalanche experts and were included in the survey (Appendix I).

1.3. Aims of the study

The overarching aims of the study are to (1) study experts' knowledge about – and use of – existing decision-making frameworks and (2) evaluate the importance of the underlying factors by use of an expert survey. The main questions this study seeks to answer are: Do experts use existing decision-making frameworks? Which, if any, of the factors

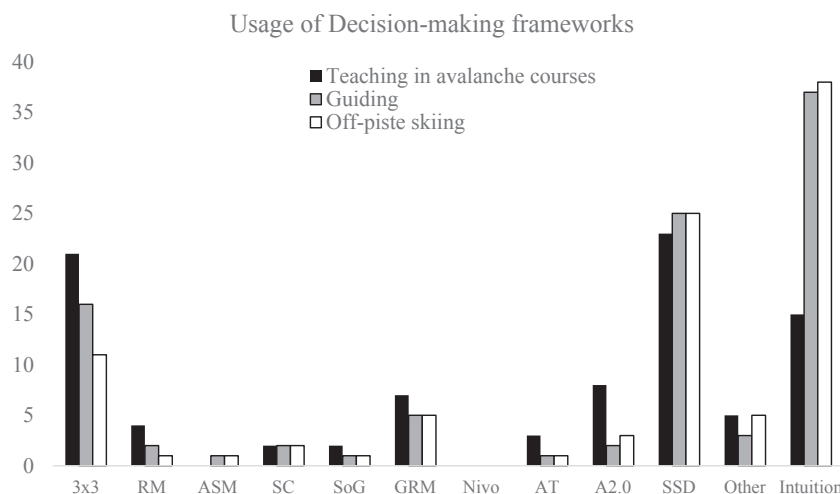


Fig. 1. Experts' stating for what they use the DMFs. Two experts wrote in the text field for other DMF: "Canadian joint decision making" and MB Achtung Lawinen, respectively.

in these frameworks do they employ?

More specifically we ask:

1. Are avalanche experts familiar with the most commonly used frameworks in Europe and North America?
2. To what extent do experts use these frameworks in their decision-making in avalanche terrain?
3. Do avalanche experts evaluate the same factors as the ones used in the frameworks, and how important are these factors in different stages of an outing?
4. Which factors are most commonly used by experts, independent of their background? And are these factors regarded as decisive, relevant, or irrelevant in the different phases of an outing?
5. Do the factors used differ between those that have experienced avalanche accidents or incidents where they or someone in their group was caught by an avalanche and those without any experience of avalanche accidents?

An expert is a person that has a large share of his/her daily work in avalanche prone terrain, performing real-life decision-making on behalf of themselves and in some cases others, and has done this for many winter seasons. An expert can typically be a mountain guide, avalanche forecaster or professional free-skier. To us, it is of great interest to know if the ones that have the most exposure to avalanche terrain actually know and use existing avalanche decision-making frameworks. It is also of interest if they evaluate and emphasize different factors in the same phases during an outing as the ones used in the frameworks.

Answers to these questions will potentially have implications for future initiatives to revise existing and develop new decision-making frameworks. It could also be of importance for the structure and content in training, both for professionals and recreationalist.

2. Methods

2.1. Participants

To ensure a thorough evaluation of the different methods and factors we recruited different expert groups, in several countries, who differ in their traditions and approach regarding decision-making in avalanche terrain. 121 participants visited the survey. Of those, 100 completed over 90% of the survey. Of those 100 participants, 10 were female and 89 men.¹ The participants were recruited among experts associated with the European Avalanche Warning Services (EAWS), or among professional mountain guides (IFMGA), ski guides, mountain

guide instructors and avalanche educators from Europe and North America. Through personal friendship, we recruited some professional free skiers. We also snowballed from established contacts. All but the Canadian respondents, who were invited and encouraged by the Association of Canadian Mountain Guides, received a personal invitation to participate. We only invited persons who were thought to be on the highest level, the expert stage, according to the five-stage phenomenological model of skill acquisition (Dreyfus and Dreyfus, 2005).

The sample was equally divided between respondents from Scandinavia ($n = 32$), the German-speaking part of the Alps ($n = 32$) and North America ($n = 35$). On average, the respondents had 28.2 years of experience in backcountry skiing, ranging from 8 to 52 years, spent 50 days backcountry skiing per season, whereof 73% were in avalanche terrain.

2.2. Survey

We created an online survey following the grouping of the underlying factors as presented in Landrø et al. (2019, this issue). Questions about a factor followed the same procedure. Firstly, we asked if a factor is part of the respondent's decision-making in avalanche terrain. If yes, we asked in which phase (planning, route, slope decision) the factor is used, and how they evaluated the factor's importance.

To reduce a possible priming effect, we asked the experts about use and importance of all the factors – randomized - before asking questions on knowledge and use of existing decision-making frameworks. In addition, we asked questions about background (e.g. avalanche related education) and skiing (e.g. exposure to avalanche terrain) and demographic questions at the end of the survey. The survey was pre-tested on 10 participants. Based on their feedback we improved clarity of questions, workflow and translations. The survey was made available in Norwegian, English and German, providing the avalanche terminology for many in their native language.

The final survey design is presented in Appendix I. The survey was implemented in Qualtrics (Qualtrics, Provo, UT).

2.3. Procedure

The survey was launched on 20th February 2018 and remained open until the 31st May 2018. Participants were contacted via email,

¹ 1 respondent abandoned the survey before the demographics section, no nationality, years of experience and gender information is available, the respondent took the survey in German.

Table 2
Overview of the 53 factors assessed in the survey, which DMFs use the factor and out of the 100 surveyed experts how many that state they are using the factor.

	Factors	DMF including it	# using factor
Snow and avalanche	Signs of instability	SoG, AT, A2.0, RM, ASM, SC, GRM, SSD	73
	Loading of new snow	SoG, NT, AT, A2.0, RM, ASM, SC, GRM, SSD	73
	Wind or rain within last 48 h	NT, A2.0, RM, ASM, SC, SoG, GRM, AT, SSD	74
	Critical warming	AT, A2.0, NT, RM, ASM, SC, SoG, GRM, SSD	80
	Signs of slab avalanches within last 48 h	SoG, AT, A2.0, NT, GRM, RM, ASM, SC, SSD	73
	Presence of persistent or deep persistent slab problem(s)	A2.0, RM, ASM, SC, SoG, GRM, NT, SSD	79
	Unusual, infrequently traveled route	NT, RM, SC, SoG, GRM, SSD	53
	Pillows wind-drifted snow/cornices	SoG, NT, RM, ASM, SC, GRM, AT, A2.0, SSD	68
	Deep snow	RM, ASM, SC, SoG, GRM, NT, AT, A2.0, SSD	67
	How snow feels when moving on skis	none	78
	Potential avalanche size	none	70
	Avalanche sensitivity to triggering	none	77
	Possible avalanche type (loose snow, slab avalanche)	none	75
	Snowpack evaluation and stability test	Hardness of overlaying snow (over weak layer)	SSD, SC, SoG, GRM
Weak layer distance from snow surface		SSD, SC, GRM	80
Weak layer grain type		SSD, SC, GRM	70
Hardness difference between layers		SSD, SC, GRM	38
Weak layer thickness		SSD	62
Grain size of weak layer		SSD	58
Fracture character		SSD, A2.0	75
Test score from stability test(s)		SSD, GRM, A2.0	38
Stability tests (CT, ECT, hand shear, little block, PST, Rutschblock, ski cut)		SSD, GRM, A2.0	92
Combination of different elements		SSD, SC	N/A
Danger level		RM, ASM, SC, SoG, GRM, A2.0, AT	66
Avalanche forecast	Main message	SoG	65
	Most exposed height level and aspect	RM, SC, SoG, GRM, A2.0, SSD	66
	Avalanche problem(s)	A2.0, SoG, GRM, SSD, (NT*)	86
	Mountain weather forecast	SC, GRM, A2.0	75
	Snow pack information	SC, SoG, GRM, A2.0, SSD	81
	Travel and terrain advice	none	21
Group and group management	Group size (small, large, very large)	RM, SoG, SC, GRM, NT, SSD	98
	Participants with low technical skills	NT, ASM, SC, SoG, GRM, SSD	99
	Participants in bad physical shape	NT, ASM, SC, SoG, GRM	97
	Group not trained in avalanche rescue	NT, ASM, SoG	99
	Participants with avalanche safety equipment	SoG, NT, ASM, GRM, A2.0	99
	One-at-a-time exposed	none	75
	Ski at a distance	none	57
	Clear directions / plan on where and how to ski	SoG, SC, GRM	84
	stopping at safe spots	A2.0, ASM, SC, GRM	94
	10 m distance from 30° ascending	SoG, SC, GRM, A2.0, SSD	34
	Safety distance ascending	RM, ASM, SC, SoG, GRM, A2.0, SSD	59
	30 m distance when descending	SoG, SC, A2.0, SSD	27
	One-at-a-time from 35° when descending	SoG, SC, A2.0, SSD	28
	Terrain	5° intervals from 30°	RM, ASM, GRM, SC, SoG, A2.0
Danger level/slope inclination		RM, ASM, GRM, SC, SoG	18
slope between 34 and 36 degree steep		none	26
Discriminating between AT /no AT		SSD, NT, A2.0	86
ATES		A2.0	72
Use of favorable terrain formations		SoG, GRM, A2.0	94
Avoiding terrain traps		AT, A2.0, ASM, SC, GRM	95
Forest density		SoG, AT, A2.0	71
Convex or unsupported slopes		NT, A2.0, SC	83
Avoiding known avalanche paths		AT, A2.0	81
Avoiding exposed routes w/o protected areas		NT, GRM	88

Abbreviation of DMFs: please see Table 1.

accompanied with an information letter explaining the background, intention and format of the survey. In addition, we briefly explained the structure and workflow of the survey as pretesting showed a need for that. Information from the information letter (Appendix II) was repeated and elaborated in the introduction part of the survey. After reading this information participants gave their informed consent. The survey could be answered with self-paced breaks. Answering took between 9 min and 2 h.

2.4. Analysis

The importance of the factors as rated by the experts is presented in absolute numbers by category and stage. To assess whether experts comply with the framework they are familiar with, we calculated a

factor profile for each expert (row 2 in Table 4) and compared it to the DMF they said they are using. Take for example a participant stating he knows ALPTRUTH. This DMF has 11 factors: signs of instability, loading of new snow, wind or rain within last 48 h, critical warming, signs of slab avalanches, pillows of wind-drifted snow / cornices, deep snow, danger level, avoiding terrain traps, forest density, avoiding known avalanche paths (Table 2). If the same participant states he uses at least 9 of these 11 factors (she/he can use all the other 42 factors not part of the DMF but assessed in the survey), we score this as a factor profile compatible with the corresponding DMF. That is, we use a minimum of 80% of agreement between factors included in the DMF and factors stated as using by the expert. We used the minimum of 80% as the DMFs vary nearly by a factor of 3 (11 factors vs 31 factors), and some factors are more similar than others (e.g. category snowpack

evaluation). The agreement between the DMF and the expert is assessed with the chi-square test.

We also performed a regression analysis with the number of factors an expert uses as dependent variable and (1) number of days in back-country, (2) proportion of days in avalanche terrain, (3) years of experience, (4) number of DMF familiar with, (5) competency, and (6) number of avalanche accidents as predictors. Based on the analysis in (Landrø et al., 2019) we counted familiarity with RM, ASM, SC, SoG, GRM as being familiar with the reduction method as a coarser grouping of the DMFs avoids spurious findings. Similarly, we counted only once if one was familiar with both AT and A2.0. We provided 10 answer options for course competencies, and ranked them into four categories at an ordinal level; recreational level, observer courses, guide courses and as highest avalanche forecasting. We consider a *p*-value below 0.05 as statistically significant.

2.5. Ethics

Participation was voluntary and consideration of privacy and consent was taken into account. All information provided was treated confidentially. The respondents could contact the first author if they had questions. The study was approved by the National data security agency, NSD number 58249.

3. Results

3.1. Demographics

Of the 100 respondents 26 identified themselves as avalanche control workers or professional rescuers, 51 identified themselves as avalanche forecaster, – researcher, or - safety consultant, 65 identified themselves as mountain / ski guide, and 14 identified themselves as professional skier or snowboarder. Multiple answers were possible. When it comes to course competencies, 16 reached recreational level, 10 took observer courses, 42 took guide courses, and 31 were at the level of avalanche forecasters. Regarding the number of DMFs an expert knows, 5 respondents stated not knowing any of the 10 DMFs we asked for, half of the respondents knew one (28%) or two (32%) families of DMFs, and 33 knew three (13%) or more (22%) DMFs. Notably, one respondent indicated not knowing any DMF but having taken a guide course. Thus, of the 100 respondents four are not experts by these two criteria, however, these four participants use at least 32 (32–43) of the assessed factors, which is more than any of the DMFs has as factors (Table 1). Accordingly, we did not exclude those participants in the subsequent analyses.

3.2. Familiarity with – and use of – existing frameworks

Our first research question was: *Are avalanche experts familiar with*

the most commonly used frameworks in Europe and North America? The majority of the experts are familiar with several DMFs (Table 3). The most known are 3 × 3 and RM (known by 68%) and A2.0 (known by 61%). The remaining frameworks are known by less than half of the respondents. This lower percentage may be explained by the relative limited use outside their countries of origin (Norway, Switzerland and Canada). 16% list other decision-making frameworks not included in the survey. One expert said that he did not know any of the frameworks.

Our second research question asked *to what extent do experts use these frameworks in their decision-making in avalanche terrain?* There is a large discrepancy between knowing and using the DMFs (Fig. 1, Table 3). The 3 × 3 is taught, but not used so much during their own off-piste skiing. Intuition is hard to teach, but used during guiding and off-piste skiing. Notably, SSD is taught, used in guiding, and off-piste skiing. Indeed, SSD has the highest use-to-know percentage at 77%, i.e. more than 3 out of 4 that learned this DMF state using it. The second and third best DMF with respect to use-familiarity are the 3 × 3 with 37% and the GRM with 34%. 1 out of 6, or less, state using the other DMFs. SSD is the only method to add value to slope-specific decisions, as 68% of the experts using this DMF consider it decisive for slope-making decisions. Less than a handful of the experts consider the other DMFs decisive at this stage. Intuition, mentioned as a decision tool by 60 experts, was considered decisive at the slope-scale by 52% of them. SSD is increasingly used from the planning to the slope-specific decision stage. 3 × 3 (and GRM), on the other hand, is decreasingly used through these stages, indicating that the overall stage concept has some value but not particularly for the go / no go decision.

Regarding the decision process itself, the large majority (89%) answered that they use a combination of knowledge-based and analytical decision-making, i.e. taking detailed observations and carefully weighting factors. 60% also said that they use intuition (Table 3), but only 32% stated that they perform risk calculations, i.e. assess the likelihood of avalanches and potential consequences. It is worth noting that for decisiveness for single slope decision-making the participants rely almost solely on SSD (74%) and intuition (52%). Many of the experts (39%) told us that their evaluation is context or situation-dependent, i.e. if it is a familiar situation they use a rule of thumb, if it is an unfamiliar situation they use analytical methods. Only 16% use rule-based decision-making, e.g. when hazard is considerable, go here. 10% stated habit and 2% deferred to more experienced or higher-up decision-making or following the decision of a more experienced team member, respectively.

Why do experts not use the frameworks? 29% stated that the frameworks are simplifications, or have a structure that does not fit the way they make decisions. 18% also said they stop the user from thinking on his/her own, and 24% said they are too limiting. 14% of the experts do not believe in the statistics used in developing the framework, or found the frameworks too complicated. Some of the experts also mentioned that the DMFs don't seem to work, that they combine or

Table 3

Number of experts reporting familiarity and usage (teaching, guiding, or off-piste skiing) of the DMFs. Multiple answers were possible.

DMF	Familiarity	Usage (relative to familiarity)	Decisive for slope decision	Usage Trip planning stage	Usage Route selection stage	Usage Slope decision stage
3 × 3	68	25 (37%)	4	23	18	12
RM	68	9 (13%)	0	2	4	1
ASM	24	4 (17%)	1	2	3	2
SC	42	3 (7%)	0	1	2	1
SoG	43	5 (12%)	0	2	2	1
GRM	35	12 (34%)	2	9	6	1
NT	27	1 (4%)	0	1	1	0
AT	27	3 (11%)	1	2	1	1
A2.0	61	10 (16%)	1	6	6	4
SSD	44	34 (77%)	23	8	26	28
Other	16	10 (63%)	3	5	4	5
Intuition	N/A	60 (60%)	31	31	53	52

are based on the wrong factors or are too limiting. On the positive side, it was reported that DMFs could help to actively go into a certain mindset, structure the decision process and prevent the user from overlooking important information or underpin intuition and gut feeling.

Do the experts teach the methods they know? With exception of the SSD (22 out of 34) avalanche experts engaged in avalanche education rarely teach the frameworks that they report to know (Fig. 1). In our survey we did not ask for any justifications for why the DMFs are not taught.

3.3. Experts' factor profile

In our third question we asked: Do avalanche experts evaluate the same factors as the ones used in the frameworks?

The experts use on average 38 factors (SD = 5.1, range 21 to 47), out of 53 identified. This is more than the number of factors consulted by any of the nine DMFs (Table 1). But would those factors match the DMF they report to be using? We compared an expert's factor profile to each of the nine DMF factor profiles. The agreements between DMF factor profiles and experts' factor profile ranged from as low as 56% for the AT (27 factors in the DMF) to 73% for the A2.0 (11 factors in the DMF).

To investigate it further, we next calculated whether an expert uses the same factors as the ones of the DMF s/he has reported to be using. If the overlap is more than 80% we refer to it as a match. The reason we report 80% and not 100% as a match is that we want to allow for some lack of precision and also compensate for the variable number of factors per DMF (e.g. "forgotten" responses, choosing a similar factor). As Table 4 (row 3) shows, there were only few matches. In absolute numbers, the SSD again stands out. Overall, experts do evaluate other factors than the ones used in the frameworks they state using (See Table 5).

We grouped the 53 factors into five categories: A) Snow and avalanche factors, B) Snowpack evaluation and stability test factors, C) Avalanche forecast factors, D) Group factors and group management factors, E) Terrain factors (Table 2). There was a large agreement among the experts about snow and avalanche factors. Of the 13 factors from this category, about 73% of the factors are used by experts (SD = 7%, median = 77%, range 46% - 77%). Around 2/3 of the factors in the snowpack, avalanche forecast, and terrain categories are used by the experts. In category D – group factors, experts use on average only 58% of the factors.

Given that the experts vary in how many factors they use (from 21 to 47) we asked whether experience or competency explains some of this variation. We performed a linear regression with the number of factors an expert uses as the outcome variable. The predictors were: 1) average days in backcountry (ordinal scale, from "up to 30 days per season" to "more than 120 days per season"), 2) proportion of those days being in avalanche terrain (0 to 100), 3) number of avalanche accidents (from "none" to "more than 6"), 4) years of experience, 5) course competency (range 0 to 3) and 6) number of DMFs familiar with, scored as 0 if not familiar with any DMF, scored as 1–5 if familiar with 1, 2, 3, 4 or 5 "families" of DMFs, where families are a) the reduction methods, b) AT/A2.0, c) NT, d) SSD or e) another, not listed DMF. Course competency, assessed categorically, was transformed into

Table 4
Comparison between DMF factor profiles and experts' factor profile.

	RM	ASM	SC	SoG	GRM	NT	AT	A2.0	SSD
Number of experts using DMF	9	4	3	5	12	1	3	10	34
Experts agree by factor profile	15	7	11	3	8	16	18	26	22
Experts using DMF & agree by factor Profile	2	1	0	0	1	0	1	2	8
Proportion	0.22	0.25	0	0	0.08	0	0.	0.20	0.24
X ²	0.488	2.074	0.382	0.163	0.002	0.192	0.493	0.208	0.07
P-value	0.783	0.15	0.536	0.687	0.964	0.661	0.483	0.648	0.791

ordinal with recreational courses scored as 0, observer courses scored as 1, guide courses as 2 and avalanche forecasting scored as 3, i.e. from very little competence to high competence.

Seen together, these six factors explained 13% of the variance in the number of factors an expert uses, $F(6,92) = 2.301, p = .041, R^2 = 0.13$. Of the six predictors, only the experts' familiarity with DMFs reached statistical significance ($\beta = -0.222, t = -2.016, p = .047$), whereby knowing five DMFs compared to knowing one DMF reduces the usage by nearly one factor (Fig. 2).

3.4. Importance of the factors in the different stages of an outing

Next, we asked the experts to evaluate the importance of each factor at three different stages of an outing: the planning stage, the route selection stage and the slope-specific decision stage. The importance of a factor could be rated either as decisive, relevant or insignificant. Not all factors can be assessed at all stages of an outing, e.g. how the snow feels when moving cannot be judged at the planning stage. We present the expert evaluation for the factors for each of the five categories. The overall usage is presented in Table 2.

3.4.1. Snow and avalanche factors

All snow and avalanche factors are considered to be an important part of experts' avalanche danger assessment and decision-making (Table 6). Only the factor; *unusual, infrequently traveled route* scores low on importance. The opposite of this factor is a *heavily tracked slope*, which is considered a go-factor by some DMFs. The other factors range from 67% - 80% in use. The factor; *how snow feels when moving on skis*, is not part of any of the DMFs, except indirectly in the SSD. To the SSD, being an analytical approach, this factor is a possible source of information regarding avalanche type, avalanche size and necessary additional load for triggering. Notably, this factor is used by 78% of the experts.

3.4.2. Snowpack evaluation and stability test factors

95 out of the 100 respondents stated that they do perform some kind of snowpack evaluation, and 98 stated that they do perform a stability test. 75 experts perform these evaluations during the route selection and 64 do it also for slope-specific decisions. The factors used by the majority are the distance of the weak layer from the snow surface (80%), the hardness of the overlaying snow (78%) and the fracture character (75%). Among the stability tests, 73 perform the ski cut, 52 the hand shear test, 51 the CT test, and 49 the ECT test. The Small Block Test of the SSD (34) and Rutschblocktest (14) are less common. As seen in Fig. 3 the frequency of performing a snowpack evaluation depends on the avalanche condition, mainly the avalanche problem and type of weak layer. The experts emphasize the importance of this information in the route selection and slope-specific phase of an outing. Unlike the frameworks that primarily use a probabilistic approach, the experts do perform snowpack evaluation and stability tests.

3.4.3. Avalanche forecast factors

Only 2% of the experts never use information from an avalanche forecast. 62% use it always and 35% sometimes. The forecast is primarily used during the planning stage (50%), less during route selection

Table 5
Importance of snow and avalanche factors categorized as decisive, relevant or insignificant during the three stages of an outing.

Snow and avalanche factors	Planning			Route			Slope		
	Decisive	Relevant	Insignificant	Decisive	Relevant	Insignificant	Decisive	Relevant	Insignificant
Signs of instability				48	21	0	49	10	0
Loading of new snow	16	43	0	39	34	0	47	15	0
Occurrence of wind or rain within the last 48 h	26	41	0	30	33	0	38	17	0
Critical warming	39	32	0	42	21	0	42	12	0
Signs of slab avalanches in the area from today or yesterday	29	22	0	37	29	0	37	18	0
Presence of persistent or deep persistent slab problem(s)	37	28	0	41	28	0	42	12	0
Unusual, infrequently traveled route	8	35	3	11	22	0	14	15	0
Presence of pillows of wind drifted snow or cornices				18	42	0	32	25	0
Deep snow (foot penetration between 20 and 40 cm)				16	45	0	27	30	0
Snow feels when moving on skis				22	39	2	34	24	2
Potential avalanche size	25	30	0	31	23	0	33	20	1
The avalanche sensitivity to triggering	24	26	0	31	34	0	52	15	0
Possible avalanche type (loose snow or slab avalanche/dry or wet)	13	35	1	32	33	1	46	19	0

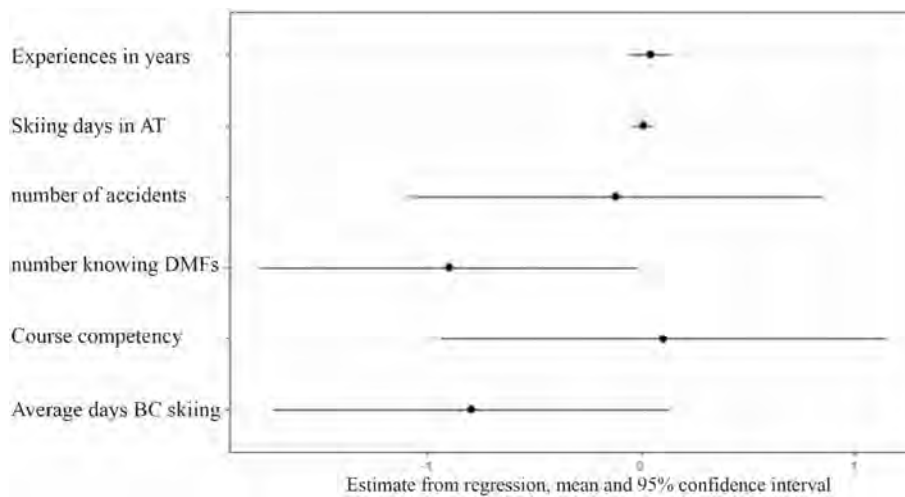


Fig. 2. Standardized coefficients and 95% confidence of the six predictors for the number of factors an expert uses.

(30%) and slope specific decision-making (20%).

A forecast consists of several factors. We asked the experts which factors they use in different stages and the importance of these factors (Table 6). The avalanche problem (87%) and snowpack information (81%) are the most frequently used factors. All factors but the travel advice (21% only) are used by more than 3 out of 5 experts. The avalanche problem is the most decisive factor at all three stages of the outing. For slope-specific decisions, the avalanche problem is rated as decisive by twice as many experts as is the exposed elevation and aspect factor, or the snowpack information. The main message is not considered a decisive factor by many, especially at the route and slope stages. Furthermore, the importance of the factor danger level gradually reduces through the different stages of an outing, with 24 respondents stating danger level being insignificant for slope-specific decision-making. The

travel and terrain advice is considered decisive at the slope stage by only one expert.

For experts the forecast factors avalanche problem, exposed elevation and aspect, as well as snowpack information are of greater importance to decision-making than the danger level.

3.4.4. Group and group management factors

We asked for importance of group factors during the planning and the slope-specific phase only. Table 7 shows that safety equipment (transceiver, probe and shovel) is the most important factor for experts. Also, group size and skiing skills are important factors to many of the experts.

When it comes to group management, stopping at safe spots is practiced by 94 of the experts, 84 give clear directions and 75 opt for

Table 6
Importance of avalanche forecast factors during the three stages of an outing.

Avalanche forecast factors	Planning			Route			Slope		
	Decisive	Relevant	Insignificant	Decisive	Relevant	Insignificant	Decisive	Relevant	Insignificant
Danger level	22	43	1	9	44	11	9	31	24
Main message	18	46	1	7	48	5	5	44	12
Exposed elevation and aspect	27	39	0	21	41	2	15	37	12
Avalanche problem	32	53	1	27	54	3	29	40	15
Mountain weather forecast	26	48	1	7	51	15	4	32	37
Snowpack information	20	58	3	15	57	6	14	48	16
Travel and terrain advice	20	1	0	15	4	0	1	11	7

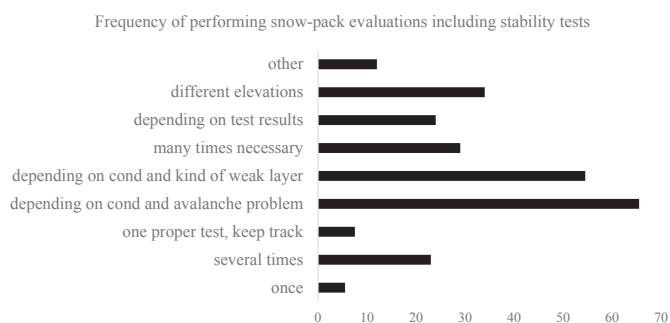


Fig. 3. Frequency of performing snowpack evaluations and stability tests (frequencies are averaged from the responses to “how often do you perform a) snowpack evaluations and b) stability test”. Cond = condition.

one-at-a-time exposure. Notably, giving clear direction is more decisive than stopping at safe spots for experts. Fig. 4 summarizes the importance of these group management factors.

3.4.5. Terrain factors

Terrain is an important factor for nearly all the experts, where the presence or absence of favorable terrain is used by 94 of the experts and presence of terrain traps used by 95 of the experts (Table 2). These terrain factors are more important at the route and slope stages, than at the planning stage.

The factor *slope inclination and danger level* plays no major role. Only 10 of the participants rate this factor decisive in planning, and the factor is seen as even less important in route and slope specific decision making. As a contrast, the experts seem to focus on the simple division of avalanche terrain and not being avalanche terrain. This broad categorization is used by 86 of the experts (Table 2) and seen as decisive or relevant for a large majority throughout the outing (Table 8). During the route and slope stage, avoiding exposed routes and convex or unsupported slopes is rated as relevant and decisive by more than half of the experts. This might indicate that experts do not look out for these terrain features during planning.

3.5. Do those with experience of avalanche accidents use different factors?

Our final research question asked *whether experts that have experienced avalanche accidents or incidents base their decisions on different factors compared to the ones which have no experience with avalanche incidents?* Avalanche exposure was measured with two items in the survey. We asked directly whether the experts have triggered an avalanche (yes/no answer option) and we asked for the number of avalanche accidents or incidents, ranging from never, once, 2–3 times, 4–6 times and more than 6 times.

In our sample 16 experts had no avalanche accident, 25 had one, 38 had two or three accidents, 17 stated 4–6 accidents, and 3 experts stated more than 6 accidents. Furthermore, 44 of the experts stated they have at least once triggered an avalanche. Thus, our expert panel

Table 7 Importance of group and group management factors.

Group and group management factors	Planning			Slope		
	Decisive	Relevant	Insignificant	Decisive	Relevant	Insignificant
Small group	26	66	6	31	54	12
Large group	35	57	5	41	44	10
Very large group	54	39	2	51	35	9
Low skiing skills	58	39	2	60	32	6
Low fitness level	58	36	3	40	42	14
Safety equipment	70	23	6	62	21	15
Avalanche rescue	47	42	10	46	37	15

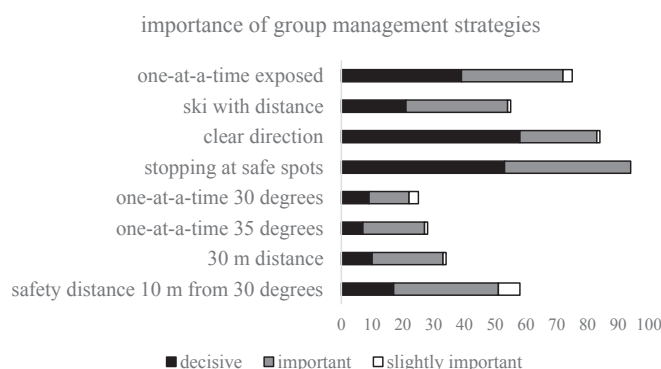


Fig. 4. Group management factors.

differed in the number of avalanche incidents or accidents they have experienced. Next, we focused on those factors at least half of the experts stated as decisive. The included factors were a) use of favorable terrain formations, b) stopping at safe spots, c) group size and skills, and d) signs of instability. We corrected for multiple comparisons, i.e. $p < .01$ is judged as significant.

Regarding the number of accidents, there was no relationship with the overall number of factors an expert uses (see also section 3.3.). A more detailed regression with number of accidents as outcome and as predictors the average number of factors used per category was not statistically significant ($p = .223$), and explained only 7% of the variance. The number of avalanche accidents did also not influence how experts evaluated the importance of factors, all p 's > 0.05 . Furthermore, the factor profile was not different between those having triggered and those not having triggered an avalanche, i.e. we found no difference a) in the importance of signs of instability (route phase: $\chi^2 = 0.552, p = .457$, slope phase: $\chi^2 = 3.194, p = .074$); or b) the use of favorable terrain formation (route phase: $\chi^2 = 3.138, p = .208$; slope phase: $\chi^2 = 5.967, p = .051$). Finally, none of the group factors (size, skills) differed between those with and without avalanche triggering experience (all p 's > 0.05).

4. Discussion

In the current paper we asked avalanche experts about their knowledge and use of the nine most common avalanche decision-making frameworks. We mapped the underlying factors of these frameworks and asked the experts to rate them in terms of importance in different stages of an outing.

4.1. Familiarity and use of existing frameworks

The results show a discrepancy between familiarity with and use of the frameworks. The experts know the different frameworks, but rarely use them. The 3 × 3 method can be regarded as an overarching structure specifically designed to cover trip planning, route selection and

Table 8
Importance of terrain factors during the three different stages of an outing.

	Planning			Route			Slope		
	Decisive	Relevant	Insignificant	Decisive	Relevant	Insignificant	Decisive	Relevant	Insignificant
Slope inclination and danger level	10	5		9	4		6	7	
Avalanche terrain vs non avalanche terrain	42	31		43	36		46	22	
ATES	3	24		5	11		3	4	
Favorable terrain formations				41	44	1	55	30	1
Terrain traps	12	29	4	40	47	2	52	29	3
Forest density	5	29	9	5	45	17	9	41	7
Convex or unsupported slopes	9	25	1	21	43	2	40	31	2
Known avalanche paths	6	33	17	6	42	10	13	25	10
Avoid exposed routes	20	42	6	23	50	4	26	31	3

slope specific decision-making, and not surprisingly several of the experts use this approach throughout the decision-making process. For the other DMFs there is some use in the planning phase of an outing, but in the most critical phase; slope specific decision-making, use and importance of these frameworks is almost non-existent. Indeed, for single slope decision-making the experts rely on intuition or the Systematic Snow cover Diagnosis. For the SSD, usage increases from the planning to the slope stage. The most obvious explanation is that the SSD uses factors that are done on site and therefore are not that relevant in the planning phase. In addition, the SSD builds on factors that experts in general rate as important and that it uses an analytical approach. This resembles how experts assess avalanches in practice.

One interesting finding from our first research question was the discrepancy between knowing and teaching the different frameworks. 65 of our participants are mountain or ski guides and therefore often responsible for avalanche education. However, even though they know the different frameworks, very few actually teach them. We find this striking, particularly since several of these frameworks are targeted at beginners. The majority of these frameworks are mainly probabilistic, rule based and considered to be well suited for novices. One of the reasons provided as an explanation for not using the frameworks was because the experts find them to be too complicated. This is a troubling statement when you compare the level of expertise of the expert to the average user. When taking into account that an outing requires much more than solely making decisions, like mastering skiing, navigation and keeping warm, it cast serious doubt about whether novices have the surplus capacity to engage in deliberate reasoning (Hetland et al., 2018). The exception in terms of teaching is the SSD, known by about a third of the participants, many of them also teach the method. A primarily analytical and knowledge-based approach is traditionally seen as less ideal for novices (McCammon and Haegeli, 2004). Therefore, the fact that it is almost exclusively this approach the experts teach is surprising.

4.2. Use and importance of factors

There is little agreement between the factors defining a DMF and the set of factors an expert rates as important. We found that the factors used in the reduction methods are not used by experts. The majority of experts take more factors into account than included in any framework. In addition, experts emphasize and rate other factors as more important than the ones used in the frameworks, particularly in the DMFs using a probabilistic approach (Tables 1 and 2). We address each of those factors below.

4.2.1. Snow and avalanche factors

Regarding snow and avalanche factors, most DMFs focus on the most obvious clues like alarm signs but do not include “how snow feels”. This factor, in addition to the alarm signs is considered to be an important part of the experts' avalanche danger assessment and decision-making. How snow feels is hard to quantify, but this factor has

potential in future DMFs as it is directly, and importantly, continuously observable. Changes in how the snow feels should be quantified.

4.2.2. Snowpack evaluation and stability test factors

Except for the SSD, snowpack evaluation and stability tests are opted out or play a minor role in all the other DMFs. In contrast, the experts are concerned about factors regarding snow: processes in the snow, snow layer properties, snow stability, weather effecting snow and avalanche problems and their distribution. Experts perform, conditional on the avalanche problem, stability tests. The results from stability tests should be part of frugal heuristics (Gigerenzer and Gaissmaier, 2011).

4.2.3. Avalanche forecast factors

To experts, an avalanche forecast is much more than its danger level. It is a starting point and source of information, an important piece in the attempt to be well prepared and have the best possible overview of the current situation. The avalanche problem is consider the single most important information in the forecast, which is in line with the findings of another recent study on communication of avalanche forecast to all user groups – from novices to experts (Engeset et al., 2018).

We interpret the experts' answers as follows; experts use different sources to identify avalanche problems (weather- and avalanche forecast, tests, signs of instability, profiles); they track these problems (signs of instability, profiles, tests and process thinking); evaluate if the problem can be handled; apply appropriate mitigation measures given the current problem.

4.2.4. Group and group management factors

Regarding group and group management factors, there are considerable differences among the DMFs whether a factor is included, its importance and how it is supposed to be evaluated and used (Landrø et al., 2019). To the experts, on the other hand, these factors are important decision-making factors and determining what options and opportunities one has, given the current conditions. The experts try to balance snow conditions, group skills and terrain. The experts use and approach to these factors resembles the “Wer geht wann wohin?” (who goes when where?), a concept used by Naturfreunde Österreich (Studeregger et al., 2016). Integrating of various interdependent factors is challenging, but can be taught step-by-step (Gigerenzer and Gaissmaier, 2011; Gigerenzer, 2014).

4.2.5. Avalanche experience

We did not find that experience of being avalanched influenced the factors used. This suggests that experts are aware of the possibilities and limitations of the factors and see the complexity and the limits of our knowledge within the field of snow and avalanches. Indeed, the number of factors used, did also not depend on backcountry experience or proportion of skiing days in avalanche terrain.

4.3. Expert approach and a road map for developing better DMFs

Our results raise the question: how does the transition from novice to expert happen? Where, how and when do experts become experts? There is probably no single or straight forward answer to this, but what we have shown is that there is a void between existing frameworks and how and on what basis experts base their decisions. The combination of factors they use, indicate that what is taught in avalanche courses is not sufficient to build up the knowledge needed to progress towards becoming an expert. However, avalanche danger assessment and risk mitigation as done by experts can be summarized by answering the questions in the following steps:

1. Is it avalanche terrain?
2. Is there an avalanche problem?
3. What are the properties and distribution of the avalanche problem?
4. Is risk mitigation possible?
5. Are the consequences of being wrong acceptable?

The way the experts assess avalanche danger has clear similarities with the process of conventional avalanche forecasting (LaChapelle, 1980). That is, the assessment is based on inductive logic, minimizing uncertainty by maximizing prior knowledge. However, this approach has a different structure than the one found in existing frameworks. The frameworks have been made with the best intentions. Still, their usage is limited, especially among experts. So far there are no comprehensive studies that compare usage among beginners, skilled users and experts, though one study assessed whether importance of factors in avalanche bulletins differs by expertise (Engeset et al., 2018). During two winters, a team from the German mountaineering organization (Deutscher Alpenverein), investigated the actual behavior of backcountry skiers in the Alps (Mersch et al., 2007). This investigation showed that the use of available and well-known, decision-making frameworks was very limited, irrespective of experience level. Similar findings were made in a study on group dynamics and decision-making within recreational groups (Zweifel and Haegeli, 2014). None of the groups in the study formally used any DMFs, although most groups applied simple heuristics based on decision rules promoted in some DMFs. Even if an ultimate framework existed, it is still up to the user to actually use it, and this can of course never be guaranteed.

Three possible ways to improve current methods or to develop new decision-making frameworks:

1. An analytical approach, based on the factors that experts use. Such an approach demands that the recreationalists acquire a high level of competence. It might be perceived as very restrictive at first. As a user, one has to accept that it will take time before one is able to exploit the whole potential of this approach.
2. A probabilistic approach. Improved risk calculations can be made, using accident data, actual terrain usage (tracks) in combination with high resolution terrain models. The Quantitative Reduction method, used on the website skitourenguru.ch is an interesting start (Schmudlach et al., 2018). If combined with up-to-date mobile phone technology this could be an interesting tool for many backcountry recreationalists.
3. A combination of the two, which could accommodate individual preferences in decision-making (Stanovich and West, 2000; Zweifel and Haegeli, 2014; Mækelæ et al., 2018).

Based on our findings we suggest that future initiatives take the following into account:

- Exploit the avalanche forecasts educational and safety potential by using forecast elements such as avalanche problems and snowpack information in addition to danger level, since agreement among observers on danger level is low (Techel et al., 2016) and danger

level is a relatively unreliable factor.

- Use the same workflow at all user levels. It should adapt to the user's level of competence, limiting novices and allowing experts to use their knowledge to handle more challenging situations. This will allow the user to "grow" with it, and not hamper development, preventing the transition between novice and expert.
- Involve avalanche danger assessment and decision-making in phases, where adjustments can be made in light of new information.
- Be based on the factors that the experts use, and not on (over-)simplifications of factors and rules alone.
- Offer a structure where relevant factors are assessed in a systematic way.
- Force the user to be transparent, thereby help avoiding thinking fallacies like several heuristic traps, overconfidence (Kruger and Dunning, 1999; Krueger and Mueller, 2002; Kahneman et al., 2011), lack of communication and more.
- Accept uncertainty, and make the user aware of this (Borchers, 2005; Pfuhl et al., 2013).

4.4. Limitations

The survey was not translated to other languages, such as French or Italian, and also not distributed to the associated avalanche expert communities. This was primarily due to limited translation capacity. However, proficiency in English should have sufficed as recent research has shown that deliberate reasoning is not affected by language (Mækelæ and Pfuhl, 2019), though the specific terminology may still favor answering the survey in one's native. Other relevant avalanche communities in e.g. Spain, Slovakia, Russia, Japan, Chile and New Zealand were also left out due to limited translation capacity and lack of key persons who could initiate snow-balling of the survey in their communities. Furthermore, we did not ask the experts how they combine the different factors, which factors are most reliable, and at how accurate the factors can be assessed (Pfuhl et al., 2011).

5. Conclusions

Avalanche expertise is not defined by knowing existing decision-making frameworks, but rather by effectively using a range of decisive factors at the right stage during an outing. In contrast to many of the decision-making frameworks, experts perform *snowpack evaluations* or *stability tests*, and consider the avalanche problem and not the danger level from an *avalanche forecast* as important in their decision-making process. The experts also pay attention to *group skills and safety equipment*, and evaluate the *presence or absence of favorable terrain and terrain traps*. Additional factors, not found in the DMFs, are frequently used by experts. Experts use more factors than found in the DMFs, and their factors are a mixture from the frameworks. Many experts stated that they use an analytical approach, while probabilistic approaches are hardly used. A majority of those familiar with the SSD are using it, especially for slope-based decisions. Apart from analytical decision-making, intuition plays a large role in the avalanche danger assessment of the experts.

The lack of use of the existing frameworks should not lead the avalanche experts or the scientific community to give up, but rather propel us towards making improved decision aids to empower people in their decision-making. Such improved frameworks should facilitate learning and development of knowledge and skill – while making sure that they make sound decisions in order to return home alive.

Data availability

Datasets related to this article can be found at <https://osf.io/2z95n/> hosted at the Open Science Framework.

Declaration of Competing Interest

All authors declare that they do not have any conflict of interest.

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We are grateful for the time and efforts the respondents spent on the survey. We also appreciate the efforts from pre-testers, improving the survey significantly. We also thank all who contributed in developing frameworks intended at helping us all to decide whether to ski or not to ski.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.coldregions.2019.102897>.

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The role of avalanche education in assessing and judging avalanche risk factors

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Conflict of Interest. All authors declare that they do not have any conflict of interest.

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ABSTRACT

Risk assessments should be based on relevant factors that can be precisely assessed. In backcountry skiing misjudgments of avalanche risk can be fatal. We tested the understanding of avalanche risk factors among 1220 backcountry recreationalists with varying level of avalanche education. They rated how precisely they could assess 11 factors commonly used by experts, and rated how relevant these factors were in assessing avalanche risk. We asked if avalanches become more predictable with more knowledge or rather are considered random events. The majority consider avalanches to be predictable, and increasingly so with more knowledge and skills. Avalanche education increased how precisely a factor can be assessed. Education was particularly important for judging the distribution of the weak layers, terrain traps, avalanche size, recognizing avalanche terrain, and where to stop at safe spots. Five factors (signs of instability, distinguishing avalanche terrain from non-avalanche terrain, inclination, terrain traps, and distribution of weak layers) were judged as highly relevant. Relevance ratings were independent of a person's avalanche education level for all risk factors but danger level. Recreationalists rated relevance like experts, thus we recommend adopting an analytical approach for recreationalists as well as experts, and discuss possible implications for avalanche forecasting and education.

Keywords: outdoor risk; avalanche prevention; risk management; danger assessment; decision-making

1. Introduction

Risk can often be mitigated and reduced if one can correctly assess the factors contributing to the risk. Generally, risk assessment and risk mitigation require knowing which factors contribute to the risk and being able to assess them precisely. Snow avalanche risk factors vary how well one

can assess them, and how relevant they are (Landrø, Hetland, Engeset, & Pfuhl, 2020; Landrø, Pfuhl, Engeset, Jackson, & Hetland, 2020). We follow McClung & Scherer (McClung & Schaerer, 2006) and refer to precision as the degree of uncertainty associated with the assessment and measurement of an avalanche risk factor, and to relevance as the importance of a factor in the overall risk assessment.

The role of knowledge and expertise for judging the relevance and assessing the precision of avalanche risk factors, is of interest to risk assessment in general and avalanche risk specifically. If recreationalists identify the same factors as relevant as experts do, then avalanche education can focus on how to assess these factors. If recreationalists think they can assess most of the factors precisely but judge important factors as irrelevant, teaching should focus on explaining the relevance of these factors. If recreationalists state that they neither know how to assess the factors nor why a factor is relevant, avalanche education must teach the how and why to ensure better decision-making and safe skiing.

If it is possible to identify which factors are predictive of avalanche risk and at the same time possible to assess with sufficient precision, these factors should be used in decision tools and taught in avalanche education.

1.1 Avalanche risk assessment

An avalanche release depends on the interaction between four main factors: terrain, weather, snowpack, and a trigger. In *terrain* steeper than 30 degrees inclination, avalanches can be triggered. Once released, an avalanche can run into much gentler terrain, the runout zone. The release areas and runout zones are referred to as *avalanche terrain*. Avalanche terrain is a relevant factor, but in the extreme case of *not* being able to recognize avalanche terrain, knowing that this is a relevant and reliable factor for avalanches does not help in judging avalanche risk.

The *trigger* is either something that weakens the snowpack (i.e., increasing temperature) or something that exerts an additional load on the snowpack (i.e., precipitation) or a combination of the two. Often the trigger is a backcountry recreationalist who adds load that exceeds the strength of the snowpack (Harvey, Rhyner, Dürr, Schweizer, & Henny, 2018; McClung & Schaerer, 2006; Schweizer & Lutschg, 2000).

A stable *snowpack* can support a high additional load (e.g., a group of skiers or a snowmobile), whereas a poor stability snowpack may avalanche naturally or with a small additional load (e.g., a single skier). Therefore, slope angle and snow stability are key factors in avalanche risk assessment and are relevant factors. Natural processes, such as precipitation, radiation, wind, and

differences in temperature, contribute to variations of snowpack properties and thus its stability. This causes spatial and temporal differences in snowpack stability. Because it is impossible to test and analyze all release areas (locations where avalanches could be released), there will always be some residual uncertainty associated with stability assessments.

These four main factors can be divided into a range of underlying factors (Landrø, Pfuhl, et al., 2020) varying in their relevance and the precision with which they can be assessed. For example, potential avalanche size is a relevant factor, but the size is not directly accessible prior to an avalanche release. Even if many avalanche situations are similar, there are still countless possible combinations of factors that should or could be assessed, not to mention that snow properties change with time and altitude and thus the risk itself changes during an outing.

1.2. Knowledge-based approach

Experts do the risk assessments based on knowledge and experience. But what about recreationalists? The traditional view has been that recreationalist have too little training and spend too little time in avalanche terrain to develop a meaningful knowledge-based approach (McCammon, 2004). A knowledge-based approach requires knowledge to see how different factors interact, as well as insight into the limitations of this knowledge, i.e., focused information seeking, cue monitoring, and responding to changes. Rapid decisions can be made if the conditions are deemed as easy, e.g., gentle terrain, low danger level, easy recognizable and manageable avalanche problem. In complex situations the risk assessment requires detailed observations and careful weighting of the risk factors. The decision-making process becomes slow and typically follows a given structure to support and systematize the process. The Systematic Snow-cover Diagnosis (Kronthaler, 2019) provides such a structure.

What complicates decision-making in avalanche terrain is limited or absent feedback, thus making it difficult to develop relevant skills through experiential learning. Backcountry recreationalists might therefore develop a false sense of confidence in their risk management and assessment skills because yet so often wrong or flawed decisions provide positive feedback: no avalanche triggered. Further, if one considers avalanches as random events, one may not see any benefit in learning about the factors relevant for assessing avalanche risk.

1.4 Avalanche factors tested in this study

A previous study identified 53 factors that either are part of a decision-making framework (DMF) or used in expert decision-making (Landrø, Pfuhl, et al., 2020). We selected 11 of these factors, which emerged as highly relevant among experts or where a well-known factor.

The factors *inclination* and *danger level* are essential in many DMFs. Inclination is of importance for fracture initiation, fracture propagation, and sliding – processes relevant for dry slab avalanche release. Without an inclination of minimum 30 degrees, avalanches will usually not occur. The danger level (1-low to 5-very high) is derived from a set of definitions and is the most prominent part of a public avalanche forecast (Engeset, Pfuhl, Landrø, Mannberg, & Hetland, 2018). The factors *avalanche terrain* (release area and runout zone) and *non-avalanche terrain* and expected *avalanche size* (1 – small to 5 – extremely large) are absent in the commonly used DMFs, but are instrumental to experts (Landrø, Hetland, et al., 2020). *Stopping at a safe spot* is one of several standard travel measures and group management techniques. Its sole purpose is to reduce overall risk. *Signs of instability*, such as recent avalanches or collapsing whumpfs, are regarded as direct evidence of snow instability and avalanche danger (MCCLung & Schaerer, 2006). When present, this is easily accessible information, and there should be little uncertainty associated with its interpretation. In contrast, *weak layer distance from surface*, *test score from stability tests*, and *distribution of weak layer* (in which aspects, elevation bands, and terrain formations the layer can be found) are associated with considerable uncertainty in their interpretation. Appropriate use and understanding the limitations of these factors require knowledge and practical experience. *Terrain traps* are obstacles or terrain features in the avalanche path that increase the consequences in case of an avalanche release. *Forest density* is a twofold factor, increasing consequence and effecting snow stability. Interpretation of the latter is associated with uncertainty and requires knowledge and practical experience.

2. Methods and materials

2.1 Participants

Participants were panelists and attendees at three avalanche seminars organized by the Norwegian Avalanche Warning Service (NAWS) at the Norwegian Water Resources and Energy Directorate (NVE) and the Center for Avalanche Research and Education (CARE) at UiT The Arctic University of Norway. The survey language was in Norwegian. Nine percent had Norwegian as second language, but deliberate reasoning is similar in native and second language (Maekelae & Pfuhl, 2019).

2.2 Survey

Given the time constraints given by the avalanche awareness seminar, we selected 11 factors and asked how precisely (1 = not very precisely, 2 = fairly precisely, 3 = very precisely) it may be assess and how relevant (1 = insignificant, 2 = relevant, 3 = decisive) the factor is for risk assessment. *I don't know this factor* was also possible to choose. Participants answered first

questions about precision and secondly relevance, or vice versa. The order of the factors was constant per seminar.

With four questions, we investigated whether avalanches are regarded as random or predictable (Ulkumen, Fox, & Malle, 2016). We asked about 1) their level of avalanche training; 2) skiing skills and exposure to backcountry skiing (range: 0 = beginner to 6 = expert skills); 3) avalanche accident involvement; and 4) demographic questions, i.e., age, gender, years of backcountry skiing, and the average number of backcountry trips during the last three seasons.

2.3 Procedure

Attendees at avalanche seminars were presented the survey in-between talks related to decision-making in avalanche terrain, where the factors were visually displayed on a large screen (Fig 1) and answering was on mobile phones. Panelists were contacted via email. The survey was implemented in Qualtrics where participants gave their informed consent.



Figure 1: Two images used in the survey illustrating avalanche factors. The left image is a weak layer of buried surface hoar. A weak layer is a precondition for fracture initiation and propagation, and therefore a relevant factor. One can measure the distance between the weak layer and surface with great precision in one location. However, the distance can vary due to wind distributing the overlying snow unevenly in the terrain, affecting the precision with which this factor can be assessed. The right image is an example of a dry slab avalanche. It is the most obvious sign of snow instability. When present, recent avalanche activity provides relevant information associated with no or little uncertainty in its interpretation. Thus, this factor is one that can be assessed with a high level of precision. On the other hand, the absence of signs of instability does not necessarily indicate stability. (Photos by Markus Landrø)

2.4 Analysis

The answer options regarding avalanche accident and incident experiences were transformed into an ordinal scale where 0 = “No, I have not been involved in an avalanche incident or accident”, 1 = “I have seen an avalanche been triggered”; 2 = “Someone I was traveling with triggered an avalanche” & “I triggered an avalanche”; 3 = “Someone I was traveling with got caught, but not buried” & “I got caught, but not buried” ; 4= “Someone I was traveling with was buried” & “I have been buried in an avalanche” ; 5 = “Someone I was traveling with got injured”; “I got injured”;

“Someone I was traveling with died in an avalanche”. If a person selected more than one option, the highest rank was used.

We analyzed each factor separately with regards to precision and relevance with avalanche education and avalanche accidents as predictors. To assess whether recreationalists and experts judge relevance similarly, we performed Bayesian Association tests with Poisson sampling (Morey et al., 2018).

2.5. Open Science

Our pre-registered analysis plan, all material and data can be found at: [BLINDED]

2.6 Ethics

Participation was voluntary and anonymous. The study was approved by the National data security agency, NSD number 233888.

3. Results

3.1 Demographics

1220 participants (64% male) completed at least 80% of the survey (580 at avalanche seminars). 45% had not experienced any avalanche incident, while 3% experienced a severe incident. Most respondents had basic avalanche education only and were rarely involved in severe accidents. Many of those who experienced severe accidents, had taken advanced avalanche courses (Fig 2). Skiing skills, average number of trips, avalanche accidents, and avalanche training level were all positively correlated ($.386 > r > .492$) and internal consistency of those four factors, i.e., ω was .735. The more people were backcountry skiing, the more avalanche training they had, and the more likely they were to have experienced an accident.

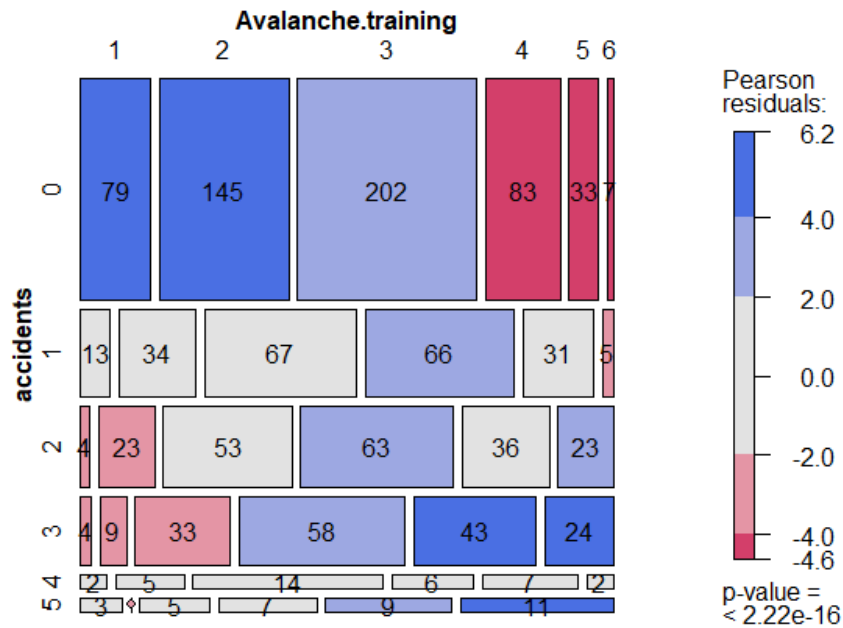


Figure 2: Mosaic plot for avalanche education by accidents. When a combination is occurring more often than expected (assuming even distribution) it is shaded in blue, when it is less than expected it is shaded in red.

3.2. Avalanches are not seen as being random

On a scale from 1 to 7, participants mostly disagreed with avalanches being a random event; the mean rating was 3.01 (SD = 1.23); in contrast the mean rating for avalanches being predictable was 5.41 (SD = 1.01). Thus, most respondents rated avalanche risk as predictable ($F_{1, 934} = 700.04$, $p < .001$, $\eta^2 = .245$) independent of their avalanche training ($F < 1$). The more severe avalanche accident a participant experienced, the less they regarded avalanches as random ($F_{1, 934} = 5.23$, $p = .022$, $\eta^2 = .001$). The interactions were not significant.

3.3. Avalanche education/training influences precision rating of avalanche factors

Overall, we found that education and training improved how well a factor could be assessed and interpreted. Exceptions were *forest density* and *stability tests*, where education/training did not affect the ability to assess the factor nor its relevance (Table 1, Figure 3). Experience with accidents played a minor role in assessing the factors.

Danger level was judged less relevant the more avalanche education a person had. The majority (recreationalists 54%, experts 65%) regarded the factor as relevant but not decisive. A test of association yielded a Bayes factor (BF_{01}) of 71:1 in favor of no difference in relevance rating between experts and recreationalists. More severe avalanche accidents lead to lower precision and relevance ratings.

Assessment of *avalanche size* improved with education and experience, but *avalanche size* was not rated as very precise to assess. Relevance rating was independent of avalanche education and accidents among recreationalists, and similar to experts, BF_{01} was 286:1.

Assessment of *signs of instability* improved with education, and was judged as decisive by the majority, irrespective of avalanche education. Relevance rating was similar to that of experts, BF_{01} was 49:1.

Assessment of the *distribution of the weak layer* improved with avalanche education but was generally not rated as precise to assess. The factor was judged as relevant by 45% and decisive by 52%, as did experts, BF_{01} was 106:1. Those with more education rated it more often as decisive.

Assessing the *weak layer distance from snow surface* varied but improved with education. The majority (62%) rated the factor as relevant, as did experts, BF_{01} was 25:1.

57% did not know what a *stability test score* is. The factor was rated as relevant but not very precise to assess. Education did not impact the rating of precision or relevance. Experts rated the relevance lower, BF_{01} was 0.5:1, neither supporting nor rejecting similarity.

Stopping at a safe spot was rated as relevant by 51% (decisive by 45%), agreeing with experts, BF_{01} was 5:1. The factor was not precise to assess, but education improved the assessment.

Assessing *inclination* was high and improved with education but not relevance. There was very good agreement about its relevance and agreement with experts, BF_{01} was 770:1.

Assessment of *avalanche terrain* improved considerably with avalanche education, whereas relevance was very high irrespective of education, agreeing well with experts, BF_{01} was 370:1.

Assessment and relevance of *forest density* was not affected by education. Relevance was high and similar to experts, BF_{01} was 48:1.

Assessment of *terrain traps* but not relevance improved with education. The majority judged this factor as decisive, agreeing with experts, BF_{01} 11:1.

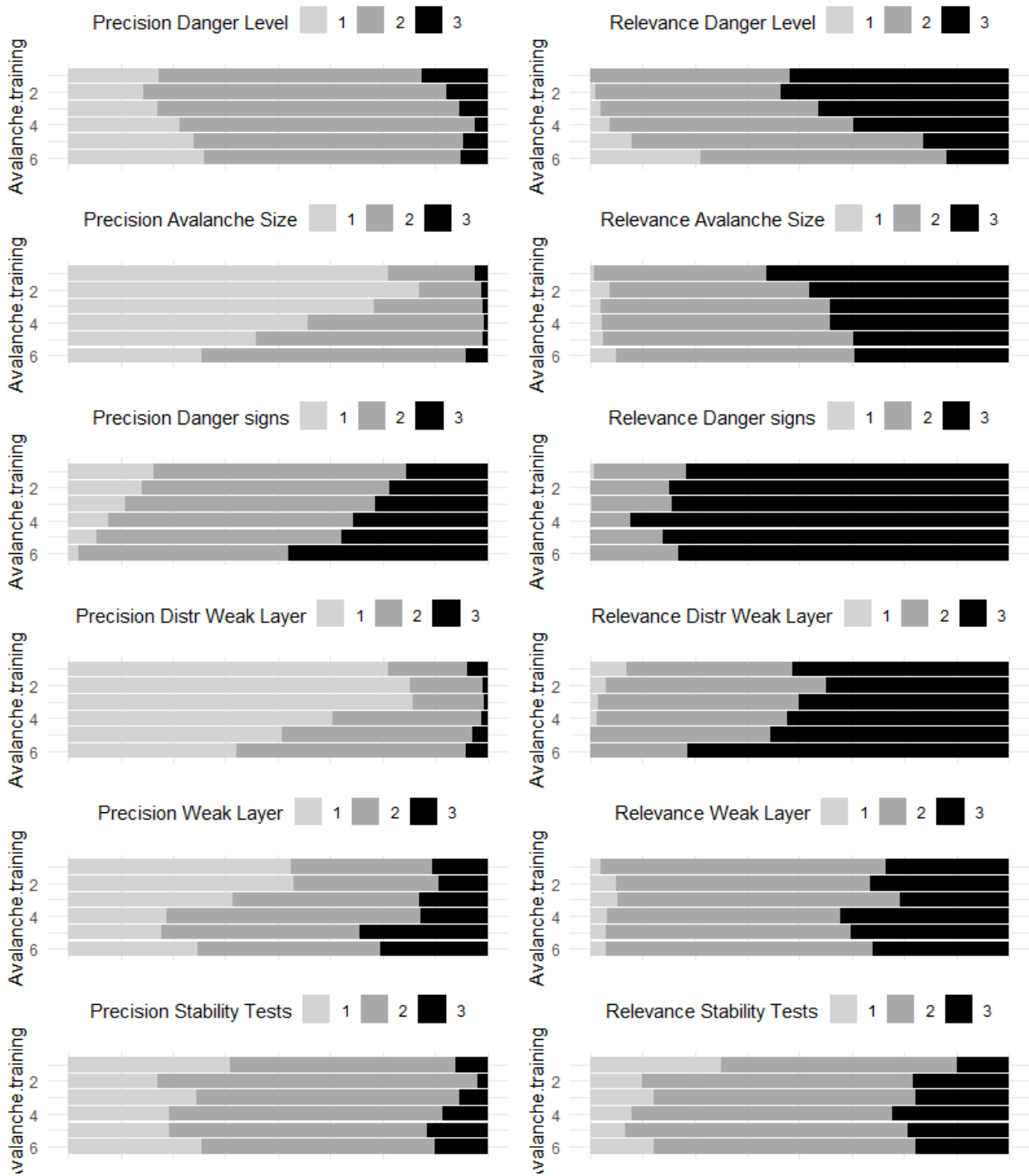


Figure 3a: Stacked barplots of first 6 factors precision and relevance separate for 6 levels of avalanche training/education ranging from none (level 1) to very advanced (level 6). Left column, precision: 1 = not very precisely, 2 = fairly precisely, 3 = very precisely. Right column, relevance: 1 = insignificant, 2 = relevant, 3 = decisive.

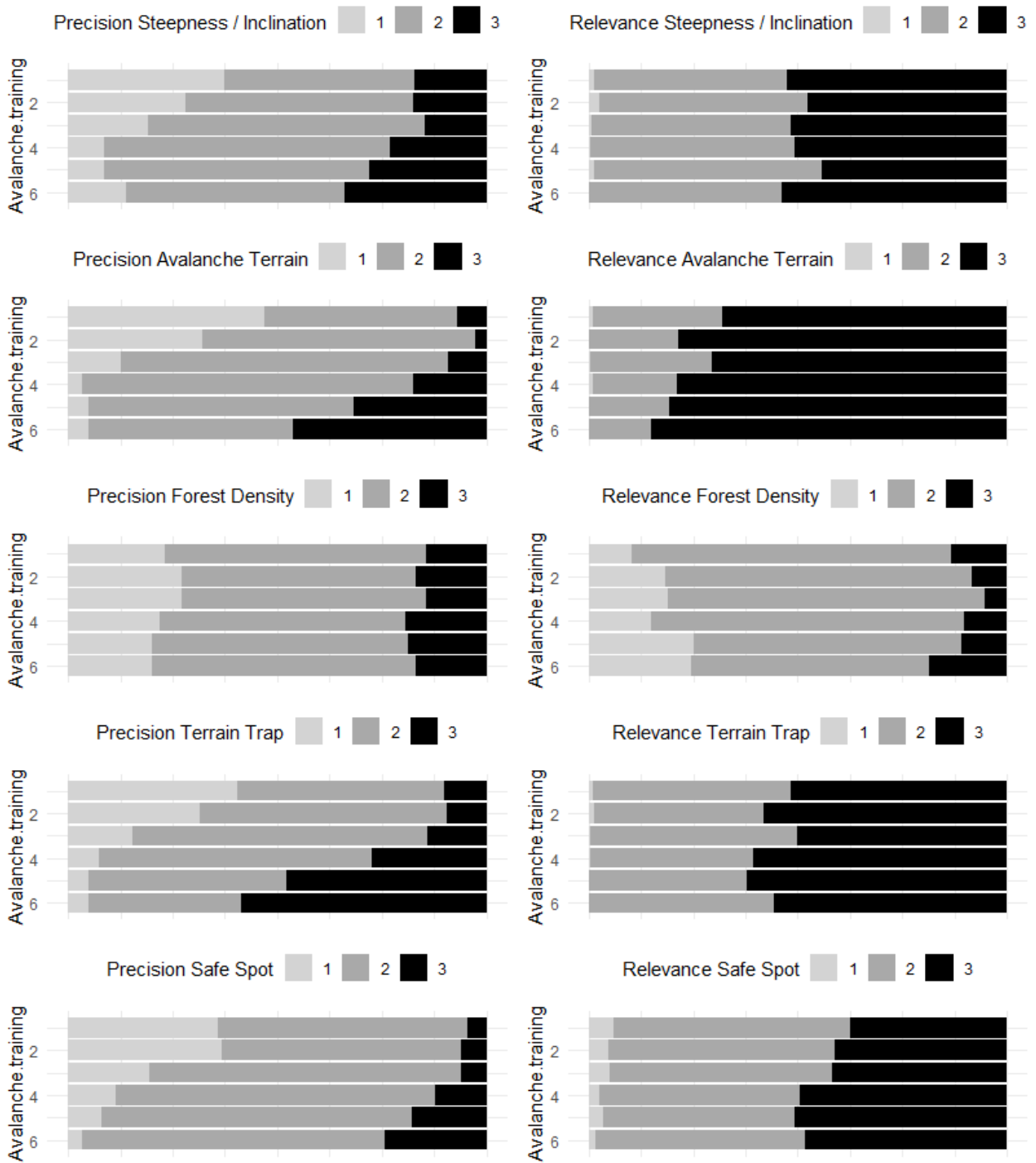


Figure 3b: Stacked barplots of the last 5 factors. For steepness/inclination the answer option “only care if it is about 30°steep” was excluded (n=170).

Table 1: Overview of the influence of avalanche training and severity of accidents on precision and relevance rating for each of the 11 factors.

Factor	Predictor	Precision						Relevance						
		R2	beta	t	p	Lower	Upper	Predictor	R2	beta	t	p	Lower	Upper
Danger Level	overall model	0.029						overall model	0.124					
	education/training		-0.092	-2.96	<.001	-0.067	-0.019	education/training		-0.236	-7.97	<.001	-0.129	-0.0782
	Experience accidents		-0.113	-3.57	0.003	-0.062	-0.013	Experience accidents		-0.18	-6.22	<.001	-0.102	-0.053
avalanche size	overall model	0.099						overall model	0.096					
	education/training		0.231	7.686	<.001	0.067	0.113	education/training		-0.1	-3.163	0.002	-0.068	-0.016
	Experience accidents		0.141	4.681	<.001	0.030	0.074	Experience accidents		0.01	0.308	0.758	-0.021	0.029
danger signs	overall model	0.031						overall model	0.003					
	education/training		0.161	5.17	<.001	0.047	0.106	education/training		0.064	2.014	0.044	0.000	0.036
	Experience accidents		0.033	1.07	0.287	-0.013	0.043	Experience accidents		-0.024	-0.075	0.455	-0.024	0.011
distr weak layer	overall model	0.065						overall model	0.022					
	education/training		0.263	7.7	<.001	0.077	0.13	education/training		0.138	3.917	<.001	0.029	0.088
	Experience accidents		-0.022	-0.063	0.527	-0.033	0.017	Experience accidents		0.026	0.748	0.454	-0.017	0.038
weak layer	overall model	0.048						overall model	0.005					
	education/training		0.198	6.35	<.001	0.075	0.142	education/training		0.073	2.26	0.024	0.004	0.059
	Experience accidents		0.043	1.37	0.171	-0.010	0.050	Experience accidents		-0.042	-1.3	0.192	-0.042	0.009
stability tests	overall model	0.004						overall model	0.003					
	education/training		0.063	1.36	0.173	-0.013	0.073	education/training		0.053	1.183	0.237	-0.017	0.068
	Experience Accidents		-0.047	-1.03	0.304	-0.057	0.018	Experience accidents		-0.024	-0.538	0.591	-0.047	0.027
steep-ness	overall model	0.054						overall model	0.002					
	education/training		0.18	5.85	<.001	0.057	0.114	education/training		0.018	0.559	0.576	-0.016	0.028
	Experience Accidents		0.091	2.96	0.003	0.014	0.068	Experience accidents		-0.05	-0.158	0.114	-0.038	0.004
avalanche terrain	overall model	0.200						overall model	0.008					
	education/training		0.385	13.6	<.001	0.139	0.186	education/training		0.078	2.459	0.014	0.005	0.047
	Experience accidents		0.119	4.22	<.001	0.026	0.070	Experience accidents		0.024	0.761	0.447	-0.012	0.027
forrest density	overall model	0.004						overall model	0.001					
	education/training		0.034	0.974	0.331	-0.017	0.051	education/training		-0.025	-0.713	0.476	-0.038	0.018
	Experience accidents		0.039	1.1	0.271	-0.014	0.050	Experience accidents		-0.013	-0.373	0.71	-0.031	0.021

terrain trap	overall model	0.197					overall model	0.003					
	education/training	0.357	12.58	<.001	0.145	0.198	education/training	0.047	1.472	0.141	-0.006	0.043	
	Experience accidents	0.157	5.53	<.001	0.046	0.097	Experience accidents	0.015	0.457	0.647	-0.018	0.029	
safe spot	overall model	0.098					overall model	0.008					
	education/training	0.258	7.76	<.001	0.080	0.134	education/training	0.086	2.452	0.014	0.008	0.068	
	Experience accidents	0.102	3.06	0.002	0.014	0.065	Experience accidents	0.008	0.238	0.812	-0.025	0.032	

Legend: Lower and upper refer to the 95% Confidence interval of the unstandardized estimate (not reported). Beta is the standardized estimate (effect size) and a beta of e.g. .3 means that one higher level in education the precision increases by .3 on a scale from 1 to 3. The first 237 participants received only eight not 11 factors.

3.4 Relevance and precision across participants

Next, we asked how consistent the factors are assessed and judged, performing a principal component analysis (PCA) with oblimin rotation. The scoring of precision and relevance from ten factors, excluding the stability test score, yielded a clear pattern. Rating of the precision and relevance of *danger level* was unrelated to the ratings of the other nine factors, i.e., these two variables made up the fourth component. The first component was the precision rating of all remaining nine factors. In other words, a participant's assessment of a factor was similar for all nine factors. The second and third component were the relevance scores of four and five factors, respectively. Overall, the PCA supported the regression results that precision and relevance are two independent dimensions.

4. Discussion

In this study, we asked 1220 backcountry recreationalist about the degree of precision with which an avalanche factor can be assessed and how relevant the factor is for their risk assessment. We compared these results with expert judgments (Landrø, Hetland, et al., 2020) and found that recreationalist judged the relevance of the tested avalanche factors very similar to experts. For all but danger level, experience with avalanche incidents or accidents did not influence the relevance judgement. Danger level was also unique as assessing and judging this factor was not related to how any of the other factors was rated. The precision rating depended for most of the factors on avalanche education, and for some factors also on experience and avalanche accidents, respectively. We discuss the findings for each of the factors before we discuss some broader implications for avalanche education and forecasting.

4.1 Understanding of the avalanche factors

The factor *danger level*, expressed as a number between 1-low and 5-very high, is not physically observable, and is obtained by reading an avalanche forecast or assessed in the field. Most of our participants judged the danger level as a factor that is low in precision. The more education and accidents the less precise and relevant the factor was rated. Surprisingly, danger level is currently not that well defined by the avalanche warnings services. In fact, the European Avalanche Warning Services are working on (1) defining the parameters required to define avalanche danger and (2) establishing the algorithm needed to derive the avalanche danger from the defining properties (EAWS, 2019). In North America, the defining parameters have been identified and explained, but the algorithm has not been defined (Statham et al., 2018). For recreationalists without any formal avalanche education, the danger level is a relevant factor, but with more training and education, the less relevant the factor becomes for one's risk assessment.

Recreationalists judged expected *avalanche size* as a relevant factor but difficult to estimate. Expected avalanche size is determined by several factors, i.e., slab stiffness, weak layer properties, destructive potential, length, area, volume, mass, or how far it runs into flatter terrain. All these properties are hard to assess in the terrain and may contradict each other when trying to assign a size category. Estimating avalanche sizes require training and experience and indeed the more training a recreationalist had the higher was the precision rating. The factor showed a decline in relevance with more training. This might be due to more knowledgeable recreationists distinguishing between avalanches that are large enough to be fatal and those that are small enough that they can be skied out. However, size matters in terms of how large a runout area one must consider.

There was a large agreement regarding *signs of instability*'s high relevance. The ability to "see" the signs and understand what causes them increased with the level of avalanche education. Still, recreationalist with no formal avalanche education judged danger signs as moderately precise to assess. No other factor received such a high precision score.

Distribution of weak layer scored high on relevance, and relevance and precision increased with education. This factor received the lowest scoring among the 11 factors for precision, and is generally associated with uncertainty in how to interpret it (MCCLung & Schaerer, 2006).

Weak layer distance from surface was neither rated as precisely to assess nor as decisive. Avalanche training did improve the ability to assess the factor. This might be due to an increased understanding of snow metamorphosis, a better understanding of snowpack variability, and the ability to interpret wind-loading patterns and the consequences this has for avalanche risk.

Those familiar with *test scores from stability tests* rated the factor as moderately relevant but not very precise to assess. Most stability tests are time-consuming and require knowledge in interpreting the results (Techel, Winkler, Walcher, van Herwijnen, & Schweizer, 2020).

Inclination (steepness) was rated as highly relevant. There are available tools and simple methods to assess inclination. However, actively using inclination measurements for avalanche risk assessment requires training and experience. Our results confirmed this by more precise assessments, the more education.

Relevance of *avalanche terrain and non-avalanche terrain* was high. The more education, the easier it was to distinguish avalanche from non-avalanche terrain. In addition to release areas (terrain steeper than 30 degrees), runout zones must be recognized to assess this factor. High-

resolution *slope (inclination) maps* in combination with computer-modeled runout zones (and possibly also release areas) available on smartphone apps simplify the assessment process of slope angle and avalanche terrain. NVEs smartphone app *Varsom Regobs* provides maps of slope angles above 30 degrees and avalanche runout zones across Norway (Larsen, Hendrikx, Slatten, & Engeset, 2020).

Forest density received the lowest relevance rating. The disparity in the results may reflect that forest density is really a twofold factor. Forest could be a terrain trap that will increase the severe consequence of an avalanche or forest could have a positive, stabilizing effect on the snow cover, which will reduce the possibility of triggering an avalanche. How one interprets the question will affect the answer.

Terrain traps increase the consequence for those getting caught in an avalanche and our respondents agreed upon the high relevance of this factor. The skill to identify terrain traps increased markedly with education.

Assessment of *safe spots* improved with education. This is a risk reduction measure that ensures safety in case of an avalanche release triggered by someone else in the group. Expedient use of this factor presupposes a high degree of understanding and reading terrain.

4.2 Implications for avalanche forecasting

Forecasting services provide the public with information on the current avalanche situation on a regional scale, serving as a starting point for the avalanche risk assessment. Forecasts follow the information pyramid structure. The avalanche danger level is presented at the top (Engeset et al., 2018). For many recreationalists, the avalanche forecast was the most critical factor in deciding to ski a slope (Furman, Shooter, & Schumann, 2010; Marengo, Monaci, & Miceli, 2017). Since the danger level is a description of the overall complexity and severity of the avalanche situation in a region the higher the forecasted danger level, the more obvious and widespread are the signs of danger. At low danger levels (1-3) the avalanche problem is more important than the danger level, while the danger level is sufficient at high avalanche danger (4-5) (Engeset et al., 2018). Indeed, experts rated the avalanche problem as the most important forecasted element (Hallandvik, Andresen, & Aadland, 2017).

The *weak layer* characteristics (its distribution, depth, and type) are important to where and how easy it is for a skier to release a dry slab avalanche. Although it is generally considered difficult to precisely assess the weak layer distribution, it is an important task for avalanche warnings services and their professional observers to discover, monitor and communicate the

existence and properties of such layers. As these factors are difficult to precisely assess in the field even for experts, the uncertainty and required caution need to be communicated in a clear and transparent manner by the warning services.

“When unstable snow is the problem, terrain is the solution”. Forecasting services should provide relevant terrain information, like release and runout areas, or avalanche terrain classification, inclination, terrain traps, safe spots/areas, and forest density. Some of these functions already exist in the Varsom Regobs app.

Forecast elements, such as avalanche problems, demand a conceptual understanding and avalanche knowledge. This should not discourage the forecasting services from presenting these elements in a more appealing and easier understandable way by e.g. using illustrative pictures and informative video-clips. We recommend that avalanche warning services have close ties to educational institutions to foster comprehension and correct use of the forecast, or even integrate educational resources in their forecasting service.

Publishing real-time field observations, not only the regional avalanche warning, can improve risk management. The NAWs provides observations in real-time, such as signs of instability, distribution and depth of weak layers, and avalanche size. This increases transparency and allows learning about the uncertainty in risk assessment. However, to support the interpretation, the competence level of the observers needs to be provided.

4.3 Benefits of avalanche education

Education clearly increased the self-rated ability to assess the factors. To have a positive *accident prevention* effect, we believe training must lead to both the development of specific skills and the ability to assess one's own skills (Norman et al., 2019). Training involves learning practical skills, the ability to detect and monitor cues, and to seek relevant information. In addition to the traditional field-based training, avalanche education should include video-based learning. This would amplify the field-based training and may compensate for situations when factors are not present or too dangerous to approach. Hazard perception skills improve significantly using both field-based and video-based training methods (Kuiken & Twisk, 2001). Video-based learning does not replace field-based learning. Crucially, instructors must provide adequate feedback and compare the students' rationale with the rationale provided by the instructor or expert (Klein & Borders, 2016). We also recommend teaching according to the principle *Who goes where when?* This principle could help communicating the need to balance situational task demands with group skills

and ability. This highlights the relationship between competence and leeway, i.e., experts being able to handle more complex terrain and challenging conditions than beginners.

To further balance skills with task demands, novel decision-making frameworks should; a) ensure that the user can evolve within the same framework, b) force the user to be transparent, c) frame decision-making questions so that the burden of proof is on the decision maker, i.e., ask” *Why is it safe?*” rather than” *Why is it dangerous?*” , which implies assuming a slope being unsafe until the assessment indicates the opposite, d) reveal uncertainty by structuring the overall assessment to arrive at one of three possible outcomes safe, unsafe, or uncertain / gray zone (the number of gray zone situations will decrease with increased competency, thus increasing available leeway), and e) offer a structure where all relevant factors are assessed, and f) accept failure as a real-world option. Residual risk and the omnipresent possibility of making decisions leading to the release of an avalanche, makes it imperative to include the question *What are the consequences if I am wrong?*

Table 2 shows the necessary learning objectives (column 2), acquired skills (column 3) that should be incorporated in any formal avalanche training, relevance (column 4), at which stage of an outing the factor can be used (column 5-7), the effect of training on understanding avalanche risk (column 8), and how easy it is to become expedient (column 9). The latter is our suggestion, based on weighting the ease of interpretation, level of uncertainty associated and the scope of learning tasks. We also recommend which factors are more suitable for video education (column 10). The following factors are high in relevance and can be effectively improved by training: Signs of instability, slope inclination, stopping at safe points, distribution and depth of weak layer, and avalanche size. Signs of instability and most terrain factors are relatively easy to learn, while stopping at safe points and avalanche terrain is more advanced and complex. The danger level is in a way easy to learn, but also transforms complex snow information and processes into one single item. Six of the factors are prime candidates for educational videos.

4.5 Limitations

Our study did not use all 53 avalanche risk factors, as we were not interested in knowledge about each factor but rather on the role of avalanche education in correctly assessing risk factors. There might be differences in self-reported and actual in-field use, addressable in future research.

Table 2: A summary with the perspective of assisting development of better education and training frameworks for avalanche risk assessments. We always recommend to complement using field-based training and experience. The ratings very high / high (relevance and effect of training), and easy / advanced (ease of learning) are in blue / light blue to highlight the most important findings to stakeholders in avalanche education.

Factor	Learning goal	Skill set	Relevance	Planning stage	Route selection	Slope-specific	Effect of training	Ease of learning	Video
Danger level	Understand concept & elements of danger level	Consider general severity of situation (planning phase)	-	√ Forecast	-	-	-	Easy	-
Avalanche size	Identify different avalanche types Understand weak layer & slab properties Understand fracture initiation & propagation	Estimate potential avalanche size	High	√ Forecast	√	√	High	Advanced and complex	√
Signs of instability	Identify signs of instability Understand what caused the sign	Awareness and interpretation	Very high	√ Forecast Observations	√	√	Very high	Easy	√
Weak layer distance from surface	Understand concept of snowpack variability Interpret wind loading patterns	Estimate likelihood of triggering Estimate necessary additional load or weakening Estimate potential avalanche size	High	√ Forecast Snow history Observations	√	√	High	Advanced and complex	-
Distribution of weak layer	Understand what to look for & where to look Understand snow metamorphosis Evaluate snowpack Do process thinking Understand snowpack distribution & variability	Assess where a specific weak layer can be found	Very high	√ Forecast Snow history Instable locations Observations	√	√	High	Advanced and complex	-
Test score stability tests	Understand what to look for & where to look Learn to do tests & interpret test scores Understand the possibilities & limitations Understand the concept of distribution	Estimate likelihood of triggering Estimate necessary additional load or weakening Estimate avalanche size	-	-	√	√	High	Advanced and complex	-
Inclination	Measure inclination (tools) Use inclination maps Use guidebooks	Estimate inclination Terrain selection Identify avalanche terrain	High	√	√	√	High	Easy	√
Avalanche / non-avalanche terrain	Use aids (maps, inclinometer, apps) Use guidebooks Do route finding, observe terrain	Identify avalanche terrain Terrain selection	Very high	√	√	√	Medium	Easy	√
Forest density	Imagine consequences Understand effect on snowpack	Know when to avoid or use to your advantage	-	-	√	√	n/a	n/a	-
Terrain trap	Imagine consequences	Identify terrain traps Terrain awareness	Very high	-	√	√	Medium	Easy	√
Stopping at safe spots	Identify run out zones Understand avalanche flow patterns Terrain know-how	Identify safe spots	High	-	-	√	Very high	Advanced	√

5. Conclusion

In high-stake low probability environment like snow-covered mountains, avalanche risk assessment requires both knowing which are the relevant factors and being able to assess those factors with sufficient precision. By studying the role of avalanche education on assessing and judging avalanche risk factors among backcountry recreationalists, we found a similar judgement about which factors are relevant and predictive of avalanches as we previously found among experts. The ability to assess the factors with enough precision often depended, and even improved with avalanche education. Recreationalists viewed avalanche risk assessment as learnable. This supports the view that analytical, knowledge-based decision-making should not be reserved for experts, but should be taught beginners as well. We recommend how to optimize education and develop better decision-making frameworks, knowing that there will always be residual risk and uncertainty, making it impossible to guarantee absolute safety.

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Communicating public avalanche warnings – what works?

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Abstract. Like many other mountainous countries, Norway has experienced a rapid increase in both recreational winter activities and fatalities in avalanche terrain during the past few decades: during the decade 2008–2017, 64 recreational avalanche fatalities were recorded in Norway. This is a 106 % increase from that of the previous decade. In 2013, Norway therefore launched the National Avalanche Warning Service (NAWS), which provides avalanche warnings to transport and preparedness authorities and to the public. Previous studies suggest that avalanche warnings are used extensively in trip and preparedness planning and have a relatively strong influence on the decisions people make in order to reduce risk. However, no evaluation concerning how efficiently the warnings are communicated and understood has been done to date in Norway. Avalanche warnings communicate complex natural phenomena with a variable complexity and level of uncertainty about both the future and the present. In order to manage avalanche risk successfully, it is fundamental that the warning message can be understood and translated into practice by a wide range of different user groups. Users with little or no avalanche competence may need simple information to decide when to stay away from avalanche terrain, while professional users may need advanced technical details in order to make their decisions. To evaluate how different modes of communication are understood, and how efficiently the informational content is communicated, we designed and implemented a web-based user survey. The modes of presentation

were based on the Varsom.no 2017 version (Varsom.no being the national portal for natural hazard warnings in Norway). We first used a panel of 110 experts from NAWS to answer the survey, and used their answers to establish the indented message of the avalanche warning. We thereafter received responses from 264 users and compared their answers to those of the NAWS experts for the different modes of communication. We developed a method, the comprehension effectiveness score, to test the comprehension. Our empirical analyses suggest that most users find the warning service to be useful and well suited to their needs. However, the effectiveness of a warnings seems to be influenced by the competency of the user and the complexity of the scenarios. We discuss the findings and make recommendations on how to improve communication of avalanche warnings.

1 Introduction

Does the Norwegian Avalanche Warning Service effectively communicate its intended message? Risk communicators should pursue their intention to assess whether the message they disseminate is appropriate, understandable and useful (Charrière and Bogaard, 2016). This is a matter of prime concern during a period of dramatic change in information technology and information consumption in society. The Internet is rapidly becoming the main source of information, and

studies show that communication is important: e.g. Brigo et al. (2016) conclude that Internet campaigns with emotional content are important to effectively promote awareness programmes on risk of avalanches and increase public knowledge related to these persistent and serious threats. This study focuses less on campaigns and more on the avalanche warnings and forecasts published daily by Avalanche Warnings Services (AWS').

In this paper we use the terms *danger* and *hazard* interchangeably. The same applies to the terms *forecast*, *warning* and *bulletin*.

1.1 Public avalanche warnings

In order to prevent avalanche accidents, AWS' throughout the world publish avalanche warnings to the preparedness authorities and the public. The standards for publishing danger levels and structuring the information in the warnings have been developed over the years with the aim of providing the users with a product that is as effective as possible. Most AWS' use the systems devised by the European Avalanche Warning Services (<http://www.avalanches.org>, last access: 9 September 2018; EAWS, 2017a, Müller et al., 2016) or the North American AWS' (<https://avalanche.org/>, last access: 9 September 2018; Statham et al., 2010, 2018). All AWS' quantify the danger into five levels (1–5) and use one or more of these standard elements: (1) a main (flash) message, (2) most avalanche-prone terrain (elevation; aspects), (3) avalanche problems, (4) snow cover and avalanche history, and (5) avalanche danger assessment and prognosis. The products from the different AWS' vary considerably in degree of detail, use of text, symbols and graphics, degree of advice provided, etc. (Burkeljca, 2013a). However, most avalanche warnings are typically structured in a standard journalistic inverted pyramid approach (Scanlan, 2000; Burkeljca, 2013b), where the most important information is presented at the top. More detailed and advanced information is sequentially presented further down in the pyramid. Accordingly, the standard EAWS approach (see <https://avalanche.org/>, last access: 9 September 2018) presents the danger level at the top, often accompanied by a flash message (a short main message). Secondly, the core zones (the most avalanche-prone terrain) are pointed out, typically by describing which elevation intervals and compass directions (sectors) have the highest danger. At this level, or at the level below, the current avalanche problems are described, followed by a description of the avalanche danger, snow cover and avalanche history, weather history and prognosis, and finally observations from the field. The pyramid approach also reflects what is useful to users at three different levels of competence (Mitterer et al., 2014): the top level of information targets all users, especially beginners with limited ability to understand and use complex information and users who want to get the key information quickly, the medium-level targets users with an intermediate to advanced knowledge of

avalanche and snow assessments, while the detailed bottom level of information is mainly useful to experts.

The danger level ranges from 1 – low – to 5 – very high (termed extreme in North America) – and is an expression of the probability and size of expected avalanches in a given geographical region over a given period of time. In order to derive a danger level, the geographical extent should be above 100 km² (EAWS, 2017a). It is a generalization over a larger area, which typically has significant local variability (Jamieson et al., 2008; Schweizer et al., 2008; Techel et al., 2016). The European Avalanche Danger Scale (EADS; EAWS, 2016) was introduced in 1993 (SLF, 2018) and is used by all European AWS' but the Swedish AWS. The avalanche warning is a prognosis of expected danger over time, typically a period of 24 h, and is based on an analysis of the current snow cover and the effects of the weather on the snow and avalanche conditions during the prognosis period. The avalanche problems (Atkins, 2004; Landrø et al., 2013; Statham et al., 2018) describe the characteristics of the avalanche danger in more detail: the type of avalanche (dry or wet, slab or loose), trigger and failure mechanism, expected terrain locations, predictability and ease of detection. The level of detail varies between AWS', as do the number of categories. Advice for back-country travellers or preparedness authorities is provided by some AWS', either in the flash message (what to be aware of or do), as part of the avalanche problem (specific advice; is the problem manageable, and if so, how) or linked to the avalanche danger level (general advice). The snow cover and avalanche analysis provides a description of the snow properties and distribution relevant to avalanche conditions (e.g. snow height, recent snow fall, surface, wet/dry, critical layers) as well as recently observed avalanches in the region (e.g. locations, numbers, sizes, types, failure planes). The avalanche danger assessment provides further details on the avalanche threats, the distribution within the region, effects of expected weather, uncertainties, etc.

Introducing the EADS in 1993 as a European standard (Meister, 1995) improved communication of avalanche danger, and provided a basis for rule-based management strategies. The danger level is used by many users (Winkler and Techel, 2014; LWD Steiermark, 2015; Procter et al., 2014) and affects decision making during back-country tours (Techel et al., 2015; Furman et al., 2010) and in the work of risk management authorities. Avalanche warnings provide important information for back-country tour planning as well as en route (Winkler and Techel, 2014; LWD Steiermark, 2015; Baker and McGee, 2016).

1.2 Warning and risk communication

The purpose of warnings is to inform people at risk about the hazard and to promote “correct” and safe behaviour (Wogalter et al., 1999). To do so, warnings may assess not only threat and danger, but also exposure and vulnerabil-

ity (WMO, 2015). Such impact-based warnings have been shown to be more effective than other types of warnings and are more in demand (DeJoy, 1999). Impact-based warnings facilitate informed decision making, which in turn leads to desirable outcomes and prevents unnecessary costs to society (Pielke Jr. and Carbone, 2002). In the case of avalanche warnings they provide users with both general and specific information about the current and expected levels of avalanche danger, the type of avalanche problem at hand, and behavioural advice. The main aim of the warning message is to inform the user about the nature and severity of current and expected threats, and about how he or she can mitigate the risk or avoid the threats. However, since most regional AWS' do not provide specific and local descriptions of the forecasted risk, it may be difficult to effectively reach this goal. In addition, most AWS' lack detailed information on the type of objects and number of individuals who are at risk, and on the exposure and vulnerability of these. Thus, most AWS' provide impact-based warnings in a general sense, but not in terms of impact specific to detailed geographical locations, people, roads, and so on. An AWS issues regional forecasts, which describe the general probability and size of avalanches in a geographical area. These forecasts may describe the general impact for recreational activity, roads, buildings, etc., but will not be able to determine the nature or scale of the impact on individuals or objects. For example, if an AWS' issues a warning at level 5 extreme danger in a mountain area where no one is recreating, the impact will be nil as nobody is exposed to the danger. At the other end, this warning describes the impact to people that are at risk, if people choose to travel in avalanche terrain in extreme danger. So in a way the forecast is impact-based, but it cannot quantify the impact specifically as the AWS' will not know how many people are exposing themselves to the risk. The warnings advise the users on how to reduce or avoid being exposed and vulnerable to the avalanche danger, and thus the risk.

Although risk communication research has been a growing field since the 1980s (Sivle, 2016), some researchers report that warning practices have not changed much during the past decades (Kasperson, 2014), and there is sometimes a gap between the intended message (warning) and the message received (Gigerenzer et al., 2007). A range of factors contributes to this gap. One such factor is that many people find it difficult to interpret numbers and probabilities. People's ability to make meaning out of numbers and statistics is often referred to as numeracy (Lipkus and Peters, 2009). Both large-scale surveys and small-scale experiments show that many individuals lack this ability (Låg et al., 2014; Kirsch et al., 2002) and that even well-educated individuals often display a low level of numeracy (Lipkus et al., 2001). One approach to mitigate this problem is to use qualitative explanations with words like “likely” and “unlikely”. Even though people vary in their understanding of such words, users can conceptualize the concepts by comparing them to risks they

already understand (Gordon-Lubitz, 2003; Edwards and Elwyn, 2001).

Another reason for a mismatch between the intended and received messages is that people vary in their motivation to use, and competence to read, warnings. The level of use and understanding of the information provided in the warnings vary between different user groups, and between different geographical regions (Wogalter et al., 1997). Geographical differences are driven both by differences in the characteristics of the user groups present in the area and by differences in the complexity and amount of supporting information provided by the regional AWS's (Burkeljca, 2013a). Differences in the use of warnings may further be driven by variations in the level of trust in authorities and experts, and by personal experiences of natural hazards (Wachinger et al., 2013). Avalanche danger may in fact be so complex that a novice will not be able to manage the same terrain as experts, no matter how well the warning is communicated. The avalanche warnings are communicating a phenomenon that many users conceive as a low-probability event, since many users never or seldom experience a release of an avalanche themselves. This conception may in itself reduce engagement on the users' side and interest in reading and using the avalanche warning, and reduce interest in investing in understanding the warning. Another challenge is that the warnings are used in several different ways, which also could lower the interest.

Taken together, these differences make it difficult for providers of avalanche warnings to meet the needs of all groups. The challenge facing providers of avalanche forecasts is made even more difficult by the lack of research on how efficient different ways of presenting the avalanche danger to different groups are. For example, less competent and motivated users may need simplified explanations and direct travel advice in order to be able to use the information. They may easily be overloaded if the warning contains a lot of detailed information (Maltz, 2000; Liang et al., 2006). For advanced users, on the other hand, simplified information and advice may be of limited use. Instead this group may demand detailed information about the snow cover. It can be challenging to simultaneously satisfy the needs of both groups.

1.3 The Norwegian Avalanche Warnings Service, Varsom and RegObs

During the past few decades, Norway, as many other countries, has experienced a rapid increase in recreational winter activities in avalanche terrain (mainly ski touring, snowmobiling and to some extent snowshoeing). The increase in back-country recreation has unfortunately been associated with an increase in fatal avalanche accidents. During the decade 2008–2017, avalanches claimed 64 recreational fatalities (61% occurred in northern Norway and Svalbard); the corresponding number for the decade 1998–2007 was 31 (NGI, 2018). By contrast, avalanche fatalities in houses and

during transportation decreased from 7 in 1998–2007 to 2 in 2008–2017 (NGI, 2018). Similar trends are reported from other parts of the world (e.g. Techel et al., 2016). Another three fatalities, all recreational, were recorded during the 2018 winter season. Thus Norway had eight fatalities the last 3 years, which brings the annual fatality figures down by 50 % as compared to the previous decade.

In other states with significant increase in the use of avalanche terrain, such as in the US and several European countries, Avalanche Warnings Services (AWS') have succeeded in avoiding an increase in fatalities, although their warning styles and formats have varied quite a bit. The trend in the US has been a declining fatality rate: whereas the number of fatalities has been rather constant, the use of avalanche terrain has surged (Birkeland, 2016).

In order to halt the undesirable trend in avalanche accidents in Norway, the Norwegian Government in a white paper in 2012 decided to establish the Norwegian Avalanche Warnings Service (NAWS) in January 2013 (Engeset, 2013). NAWS publishes regional avalanche warnings for Norway, including Svalbard, on a daily basis on the web portal <http://www.varsom.no> (last access: 9 September 2018) (Johnsen, 2013). The Norwegian Water Resources and Energy Directorate owns and operates NAWS in collaboration with the Norwegian Public Roads Authorities and the Norwegian Meteorological Institute. The reduction in annual fatalities during the previous 3–4 years suggests that NAWS is effective, as the accident numbers have not increased although the use of avalanche terrain for ski touring has increased drastically in Norway, every year during the last decade or so.

In 2017, regional avalanche warnings were issued for 21 regions in Norway (Fig. 1). In addition, warnings were issued for the rest of the country when the avalanche danger was expected to reach danger level 4 or 5. An example of an avalanche warning on Varsom.no is shown in Fig. 2. The avalanche warning published on Varsom.no includes the elements described in Fig. 2 and Table 1.

Four elements (danger level and main message, region map, avalanche problems, and mountain weather prognosis) are available in an English version of the warning on Varsom.no, while two elements are in Norwegian only (avalanche danger assessment and snow cover history) and one is partly in English (RegObs-feed with observations).

All text but that of the main message and the avalanche problems is written manually by the NAWS forecasters. Sometimes forecasters use parts of the text from the previous day, especially in the snow cover history. The text in the main message is produced in the following manner: the forecasters get a list of text suggestions that are available depending on the chosen danger level and avalanche problem(s). He/she may choose to use text from this list and edit it, write the message from scratch or copy the text from the previous day. The text in the travelling advice in the avalanche problem is generated from a list of text suggestions. The selection of text is based on the combination of the chosen danger level

and avalanche problem. The forecasters may edit the text afterwards. NAWS generates text suggestions in the forecast editing software for the main message and avalanche problems in order to make the text in the warnings easier for the users to read, ensure that the terms and wordings are as good and consistent as possible, make sure the time needed to produce the text is not too high and make translation of the text to English as good and as easy as possible. NAWS has been having discussions about the degree to which text is to be created from scratch by individual forecasters or rather be pre-defined or suggested from a standard library of sentences and terms. NAWS uses a hybrid approach to this, and the creative from-scratch text is mostly found in the main message (Norwegian and English; the English version is sometimes an extended version of the Norwegian in order to incorporate more detailed information about the snow cover and avalanche danger), avalanche danger assessment (Norwegian only) and snowpack and avalanche history (Norwegian only). However, creative text may suffer from poor language and significant individual differences that are difficult for the users to understand. Also, much time may be spent writing text to convey a message that has already been written in a much better way by someone else. However, the interest and motivation of users may drop if they get the feeling that too much text is auto-generated or copied and pasted. NAWS is aware of this effect and continuously makes efforts to prevent this from happening.

Since the start in 2013, NAWS has continuously worked to improve both the competence level of observers and forecasters, and the system for presenting the forecast. User feedback suggested that most users find the warnings useful and of high quality. However, to date, no formal evaluation has been done of how effective NAWS is at communicating its intended message. Such an evaluation is important, as public avalanche warnings have only been available in Norway since 2013 and Norwegian users are less used to using the warnings to manage risk than users in countries with a longer history of public avalanche warnings.

In order to improve the avalanche knowledge in the Norwegian population in general, and the ski touring and snowmobiling communities in particular, NVE launched the “Snøskredskolen” (avalanche school) on Varsom.no. The avalanche school is a tailor-made resource for users of the avalanche warnings, as all key terms and concepts are explained and safe travelling advice is provided. It is also a much used resource for avalanche course providers.

As a system in the Varsom.no portfolio, RegObs provides data from the field as a basis for making forecasting decisions. RegObs is an open web- and app-based system for reporting, storing, querying and sharing observations and assessments from the field with the forecasters and the public. The observations are public and a live feed of observations is displayed on Varsom.no, next to the avalanche warning. As such, RegObs is an integral part of Varsom.no and the communication of the avalanche warnings. RegObs commu-

Table 1. A description of the elements included in the avalanche warning on Varsom.no. Figure 2 shows how the elements are shown in relation to each other on a smartphone web browser.

Element	Description
1	<i>Danger level and main message:</i> the danger level is a combination of the probability and size of expected avalanches in the region during the forecast period. The main message is a flash message displayed next to the danger level, and is a short statement of what constitutes the hazard and what the advice to the user is. This text is supposed to be very short and to the point, as if the user did not care to or have the competence to read the rest of the warning. The English version of the main message may be longer than the Norwegian, in order to include details about the snow cover that are otherwise accessible in Norwegian only.
2	<i>Avalanche danger assessment:</i> a more detailed description of the avalanche hazard and what is the reason for it. It often includes a more detailed description of the uncertainty and local variability.
3	<i>Region map:</i> a map of the region, showing its extent and perimeter.
4	<i>Avalanche problem(s) with management/travel advice:</i> the avalanche problems, which at the time were storm slab, dry loose, wind slab, wet slab, wet loose, persistent slab, and glide avalanches (Landrø et al., 2013). A number of properties are forecasted for each avalanche problem: expected (destructive) size (1 to 5), expected additional load (natural, low or high), distribution (isolated, few, some or many steep slopes), release probability (possible, probable and likely) and core zone. Each avalanche problem has a pre-defined management and travel advice according to danger level. A main characteristic of the avalanche problem in the Norwegian warnings is that the properties of the weak layer are specified for slab-type avalanche problems, according to the Systematic snow cover diagnosis system (Kronthaler et al., 2013). The different avalanche problems have danger-specific advices for the users: How predictable and easy to detect is the problem in the field? Where in the terrain is it easy to trigger or be caught by avalanches from this problem? How to reduce the vulnerability to the problem? What should preparedness stakeholders be aware of?
5	<i>Snow cover (and avalanche) history:</i> this is a mixture of observation and an analysis of the snow cover at the initial time of the forecast period. It is an important baseline for making a prognosis of how forecasted weather may affect the avalanche danger during the forecasting period. It includes observations of recent avalanche.
6	<i>Mountain weather:</i> this is the weather prognosis accessed at the time of writing the warning, and is thus the basis for prescribing the avalanche danger in combination with the snow cover history.
7	<i>RegObs observations:</i> a real-time feed of observations submitted to and shared by the RegObs system. RegObs is the national system for sharing field observations in real time (Ekker et al., 2013).

nicates the field observations and assessments that the warnings are based on, in a transparent way. As far as we are aware, RegObs is the only open-access online real-time distribution system for avalanche forecasting observations right now, although previous efforts have provided open access to accident data (Duclos et al., 2008). As far as the authors are aware, there is no other completely open-access online real-time distribution system. Other systems, such as the InfoEx, the Mountain Information Network and the Mountain Hub, lack open APIs or restrict access to functionality or data partly or fully.

1.4 Aims of the study

The current study is part of a larger project, which focuses on communication of flood, landslide, and avalanche danger warnings. In this study, we evaluate the efficiency of warnings by the NAWS on the website Varsom.no. Avalanche warning systems are used in trip and preparedness planning, and have been shown to have an influence on the decisions

people make in order to reduce risk (e.g. Furman et al., 2010; Marengo et al., 2017). Mountain guides, course providers, rescue services and avalanche observers report that people actively respond to the avalanche warnings on Varsom.no, and to a large degree choose snow, terrain and time/day for travelling according to the danger level, avalanche problem and advice provided by NAWS.

Warnings should therefore ideally be revealing and unambiguous. To assess whether the warnings published by NAWS fulfil these requirements, we asked the following research questions: (1) which risk factors are considered most difficult to assess and manage? (2) Which elements in the warning are considered most and least important? (3) Which elements are easily misunderstood or considered poorly communicated? (4) What kind of information and features are missing or ignored by users?

We tested whether users interpreted the danger and behavioural implications differently depending on whether the message was described by text, by symbols or by pictures.

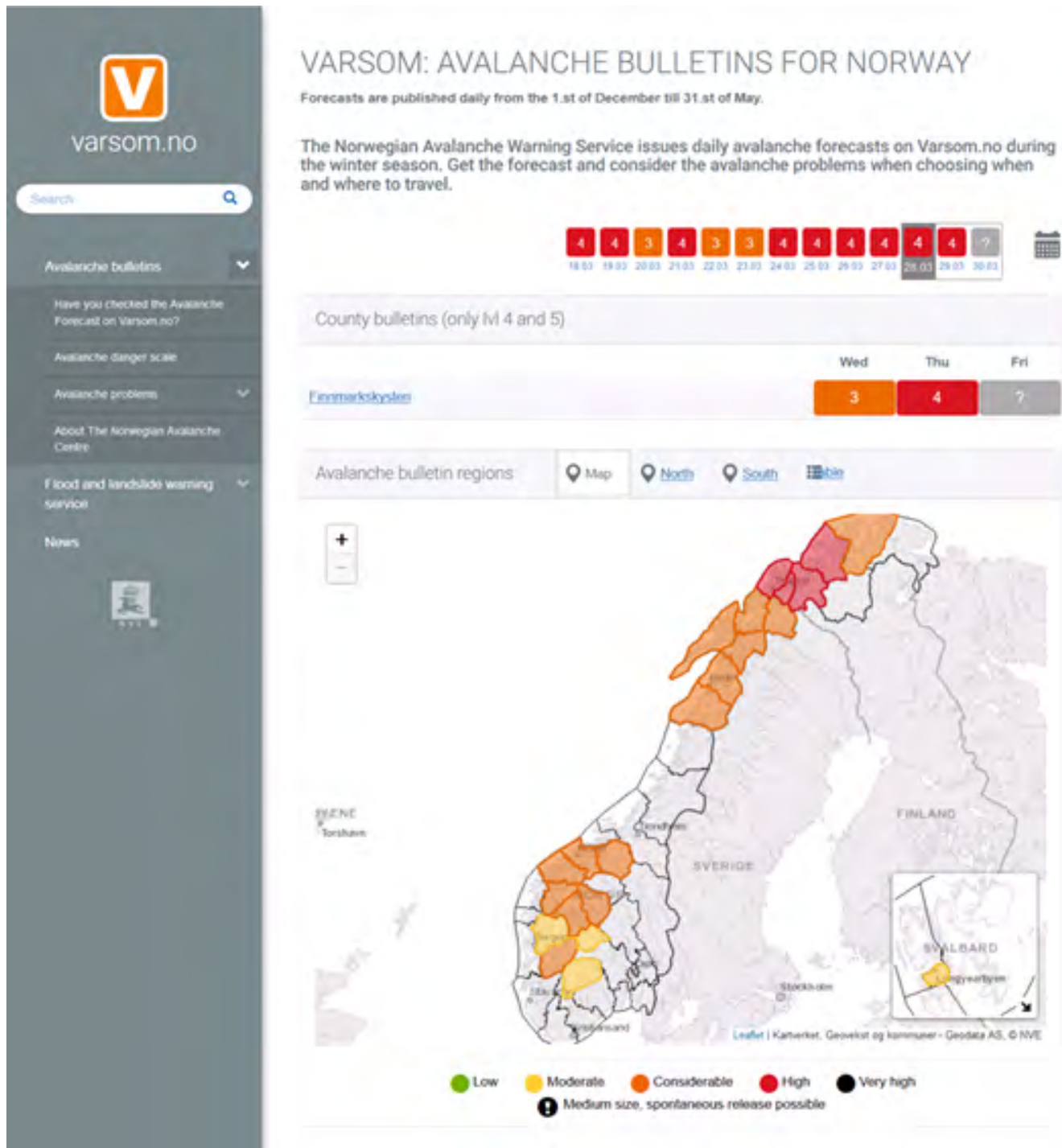


Figure 1. Screen dump from Varsom.no showing the avalanche warning regions in Norway. Daily warnings are published for the regions coloured according to the danger level. The other regions (grey) are monitored and warnings are only published at danger levels 4 and 5.

Furthermore, we tested how well the warnings were understood, by testing four alternative ways of communicating two different danger scenarios. We developed a method, the comprehension effectiveness score, to test the comprehension.

2 Methods and data collection

We developed a web-based questionnaire and survey to collect data for the study. Questionnaires are useful tools for acquiring information on public knowledge and perception

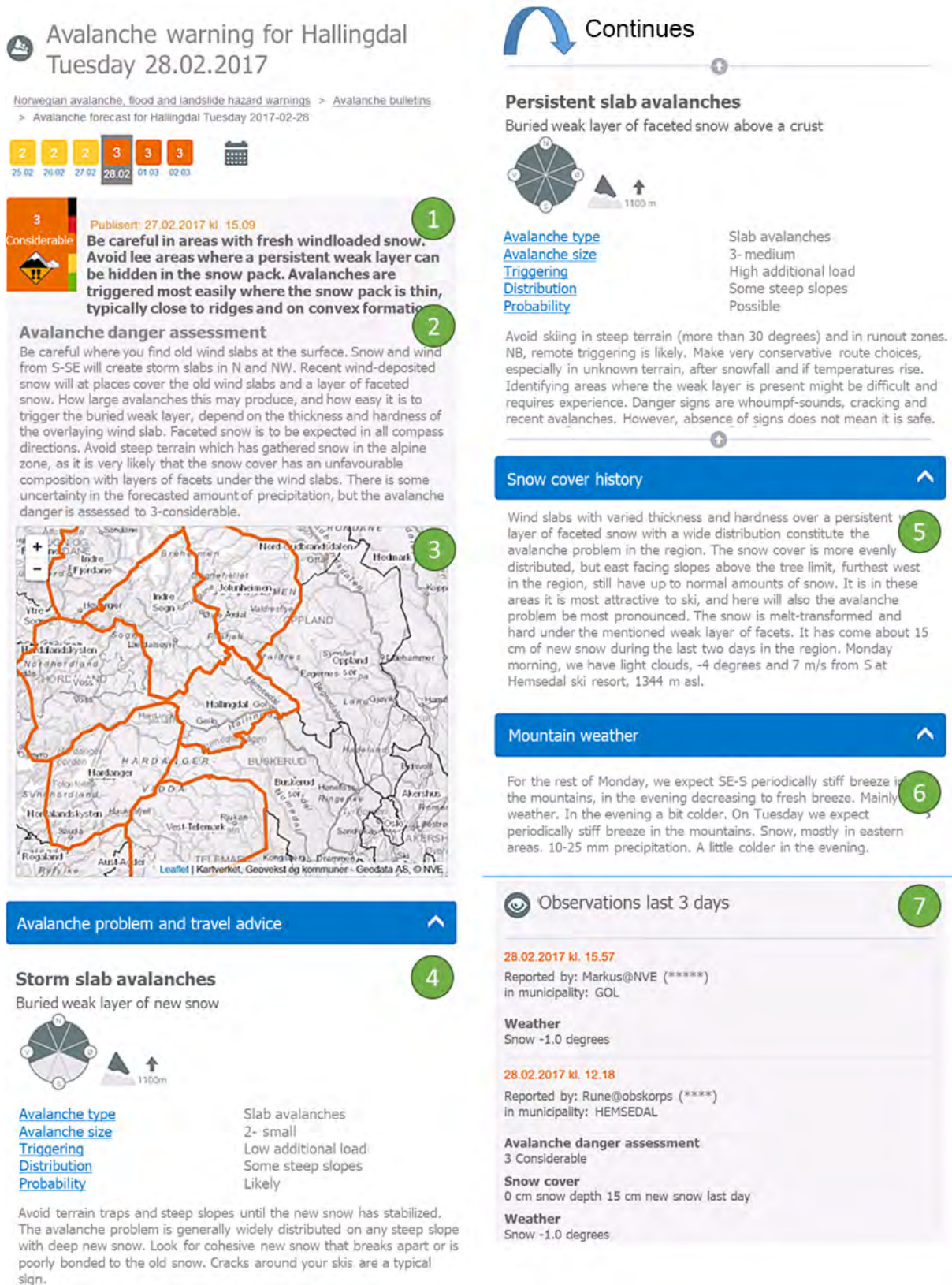


Figure 2. An example of an avalanche warning as issued on Varsom.no in 2017. The numbers refer to the elements analysed in this study. (1) Danger level and main message, (2) avalanche danger assessment, (3) region map, (4) avalanche problems, (5) snow cover history, (6) mountain weather prognosis and (7) RegObs-feed with observations. The figure shows the screen dump from a smartphone, with the middle and right panels showing the screen as the user scrolls down the page. The warning has been translated from Norwegian to English.

of natural hazards, and can provide valuable information to emergency management agencies for developing risk management procedures (Bird, 2009). This chapter presents the methods, participants and survey design of this study.

2.1 Participants

NAWS personnel participated in the expert survey (personal invitation only), while all types of users participated in the user survey (open invitation, anyone could participate). The user survey participants included all types of users (various degrees of competence and experience, from beginners/novices to experts; various types of use, from recreational to professional and preparedness), while the NAWS expert survey included only forecasters and observers, all trained in the same system.

2.1.1 NAWS expert survey

The aim of the first survey was to derive a set of “correct” answers to questions on the meaning of the presented warnings. We therefore invited 200 avalanche experts (mainly avalanche forecasters and observers in the NAWS) to participate in the survey during the period 15–26 October 2017; 110 experts provided complete responses. Of these, 67 were observers, 21 forecasters and 22 were not active in the forecasting. The last group consisted of former forecasters and observers, and of individuals with a professional liaison role in the forecasting services. Of those providing details about gender, 25 % of the participants were women and 75 % were men.

2.1.2 User survey

The purpose of the second survey was to test how well the NAWS message was understood by non-expert users, and therefore targeted users, and potential users, of the NAWS. We recruited participants via social media, Varsom.no and different user-related web pages.

A total of 485 respondents answered the user survey. Not all respondents answered questions in all sections, leaving 264 respondents for analysis of Section B (avalanche warning), 222 respondents for analysis of Section C (text versus symbols and pictures) and 177 respondents for analysis of Section D (comprehension). The lower number of user respondents completing Sections C and D reflects a common challenge in web-based surveys to engage participants enough to answer complex and time-consuming questions.

Of those providing details about gender, 17 % of the participants were women and 83 % were men. The mean age in the sample was 35 years (min = 19, max = 69); 26 % of the respondents lived in northern Norway, 8 % in Trøndelag, 11 % at the north-western coast, 24 % at the western coast, 27 % in the south-east, 1 % on Svalbard, and 2 % answered other.

2.2 Survey design

In order to obtain valid responses and avoid careless responding, it is important that participants are motivated to take the survey, understand all questions, feel that they can answer the questions, and do not lose interest before the end of the survey (Meade and Craig, 2012). We therefore pretested and revised all survey items in an iterative process. In the first stage, NAWS personnel, both forecasters and observers, provided qualitative feedback on how well the avalanche warnings communicated the message that NAWS would like to disseminate, and this was taken into account when the questions and response alternatives were designed. We thereafter asked a test panel consisting of project members ($N = 12$) to provide iterative feedback on the content and structure of the survey. Based on the feedback from the NAWS personnel and the test panel, we rephrased several questions and instructions to improve clarity. We also reduced both the number of questions and response alternatives. The latter shortened the completion time of the survey to about 10 min. The survey was constructed so that it was possible to view and answer all questions using a variety of devices, including smartphones. The general structure and purpose of each section of the NAWS expert survey and user surveys are described below.

The five sections (A–E) were identical in the NAWS expert survey and the user survey. Sections B–D provided the core data for the analysis in this paper. An overview of the survey is provided in Table 2.

The two scenarios in Section D were based on accessing the warnings (in Norwegian) on Varsom.no at the time of the survey (autumn 2017). The four alternatives given for each of the two scenarios in Section D were picked randomly for each user respondent. We did not counterbalance the order: all respondents received first the level 2 scenario and then level 4, but with different alternatives for each scenario.

2.3 NAWS expert survey

As briefly mentioned above, the main purpose of the expert survey was to derive a template of “correct” answers. More specifically, we wanted to identify key information elements and define sets of behavioural implications in different avalanche danger scenarios. In other words, we used the experts to operationalize the intended content of the avalanche forecasts. To make sure that the operationalization was valid, we used a relatively large and heterogeneous group of avalanche experts.

To limit completion time and mental strain for participants, we only used two avalanche danger scenarios (level 2 and level 4; see section D in Table 2). Each expert was randomly exposed to one out of four alternative ways to present the forecast for each danger level (Fig. 3): (1) avalanche danger level with explanation, (2) avalanche problem with tech-

nical details, (3) avalanche problem with technical details only, and (4) avalanche problem with advice only.

After the expert respondent had read the example, we first asked him or her to rate how well the danger was communicated in the example, on a scale from 0 to 10. We thereafter asked the expert to identify key information elements and behavioural implications of the avalanche forecast. The options were pre-defined, as described in Table 3. We were specifically interested in identifying the most important message that the forecast aimed to communicate.

2.4 Communication effectiveness score

In order to establish a communication effectiveness score, we used the NAWS expert answers to allocate weights to the different behavioural implications. We allocated a positive weight of +1 to elements positively identified as important by more than one out of three experts (33%), and a weight of -1 to elements positively identified by less than one out of five experts (20%). All other elements were given a weight of null.

Our reasoning behind using positive and negative weights to calculate the communication effectiveness score is that there is no objective correct answer. Accordingly, we use the NAWS expert answers, where a factor receives +1 if the majority of experts provide support, 0 for inconclusive support by the experts, and -1 if a small minority of experts regard this factor as relevant. The rationale behind this approach was to give a penalty (a weight of -1) to statements that were selected by few/no NAWS experts and a point to statements that were selected by many NAWS experts. In the design phase, we explored using different algorithms for calculating the scores, for example by using the relative number of experts selecting the statement as a weight or decimal weights. However, in order to keep the method and results relatively easy to understand and interpret, we choose a straightforward approach.

The expert choices and resulting weights are listed in Table 3. As can be seen in Table 3, many experts agreed on the most important implications, and very few items are therefore close to the cut-off value. Nevertheless, to ensure that our results do not hinge on our chosen levels (33 and 20%), we have tested both upward and downward variations of the cut-off values. The results presented in Sect. 3 are robust to these variations.

2.5 User survey

The user survey was open to the public during the period 1 November–15 December 2017. We published links to the survey on a relatively wide set of platforms: *Var-som.no*, the free online skiing magazine *friflyt.no*, and on the Facebook page of the most popular weather service in Norway, *YR.no*. The association of snow scooter clubs (*Skuterklubbenes fellesråd*) and the Norwegian Hiking Asso-

ciation (DNT) kindly distributed the survey to their members. Finally, we announced the survey on the Nordic avalanche conference in Åndalsnes in the beginning of November.

Each participant was asked to answer the full survey (Sections A–E). In Section D, the users were, just like the experts, randomly exposed to one out of four alternative ways of presenting the avalanche warning for the level 2 and level 4 scenarios, and thereafter to first rank how well the danger was communicated on a scale from 1 to 10, and to mark the most important behavioural implications of the warning.

We used the weights in Table 3 to calculate a “communication effectiveness score” for each participant and each behavioural implication. To illustrate, consider a user respondent who ticked the boxes for statements 1–3 after reading an example of the level 2 scenario. Based on the scores in Table 3, we would give this user a score of -1 (the sum of $-1 + 1 - 1$). If the user instead ticked the boxes for statements 3 and 5 after reading an example of the level 4 scenario, we would give him or her a score of +2 (the sum of $+1 + 1$). The scores for the level 2 scenario ranged from -4 to +4, and for the level 4 scenario from -6 to +3.

2.6 Web survey or field testing

Our overarching aim for this study was to investigate users' comprehension of the warning. Ultimately, all public warnings aim at making people take the correct actions at the correct time. However, there is a large body of evidence demonstrating that there is a mismatch between what people say and what they do (e.g. Jerolmack and Khan, 2014). Therefore, if we studied people's behaviour and not comprehension we would not know whether the lack of correct action was due to lack of comprehension or rather a mismatch between attitudes and behaviour.

Self-reports are by many accounts not a perfect method, but in this case we found them to be the best approach to test people's comprehension. In addition they allow us to collect a substantially larger number of respondents compared to for example a field study or interviews. A web-based survey is also relevant, as many decisions are made based on reading the avalanche warning on the web ahead of getting into navigation in the terrain. It could be decisions such as to choose forest rather than alpine for today's trip, or to delay the planned trip a few days until the snow stabilizes. However, it would be very interesting to test what people know and also what they do. This would call for a different study altogether, but is a very good idea for future research.

2.7 Ethics

This study registered anonymous information exclusively and did not collect data that can be used to identify individuals. All respondents actively gave their consent for the use of the data for research and the project.

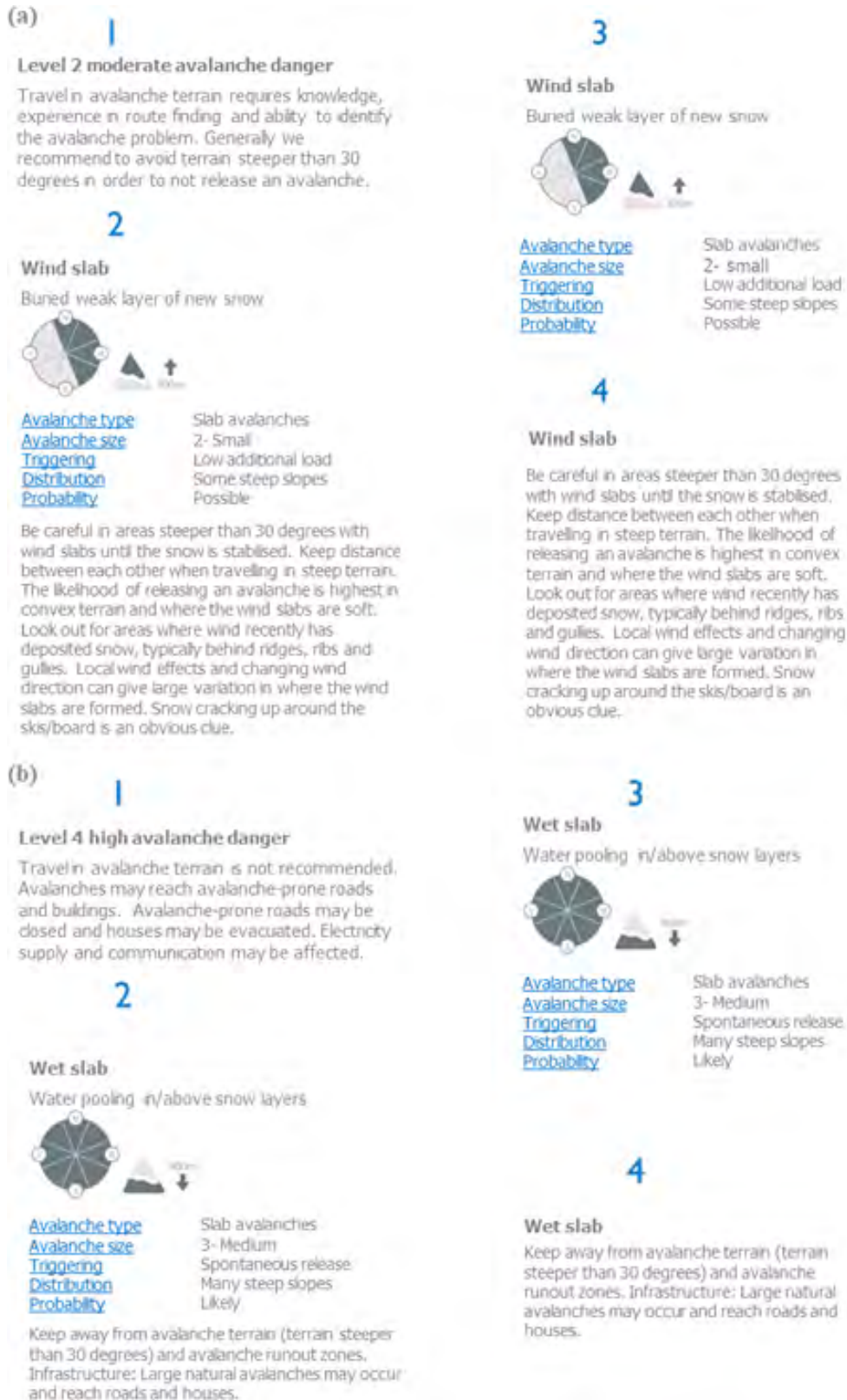


Figure 3. Alternatives 1 to 4 used for the two scenarios: (a) level 2 and wind slab (upper panel) and (b) level 4 and wet slabs (lower panel). The text has been translated from Norwegian into English.

Table 2. Overview of the survey.

Section	Purpose
A	Collect background information related to avalanche training and competence, e.g. association with NAWS, if any, level of avalanche competence and training, activity level in terms of travelling in avalanche terrain, and level of comprehension of avalanche terrain.
B	Understand how respondents evaluate the available elements in the warning and how these are communicated (which elements are most important, least important, difficult to assess and manage, poorly communicated or easily misunderstood, and which elements are missing).
C	Test how users perceive three different ways of presenting the avalanche danger: text, symbols, and pictures.
D	<p>Test the comprehension of two scenarios:</p> <ul style="list-style-type: none"> – danger level 2 (wind slab problem), based on the warning for Troms region on 18 April 2017, and – danger level 4 (wet slab problem), based on the warning for Troms region on 4 April 2017. <p>For each scenario, the participant was first randomly presented with one out of four alternative ways of communicating the danger:</p> <ol style="list-style-type: none"> 1. Avalanche danger level with explanation (general advice associated with the danger level), 2. Avalanche problem with technical details (avalanche rose, probability, distribution, expected size and type of avalanches) and advice (advice on how to manage the problem including travel advice), 3. Avalanche problem with technical details only, and 4. Avalanche problem with advice only. <p>We thereafter asked the respondent to interpret and evaluate the warning in terms of (1) behavioural implications (based on a pre-defined set of options), (2) how well the avalanche warning was presented, and (3) how the respondent would describe the warning to others, and what travel advice s/he would give to them.</p>
E	Collect background information related to demographics, and back-country recreation, e.g. gender, age, home region, terrain activities, and use of avalanche gear and forecast.

Table 3. Expert survey results (number of respondents selecting the statement, in %) and design weights established for a communication effectiveness score.

Statement	2 scenario response	2 scenario weight	4 scenario response	4 scenario weight
1. Unngå alle løsneområder (<i>avoid all release areas</i>)	20 %	−1	84 %	+1
2. Unngå noen løsneområder (<i>avoid some release areas</i>)	63 %	+1	9 %	−1
3. Unngå alle utløpsområder (<i>avoid all runout areas</i>)	8 %	−1	84 %	+1
4. Unngå noen utløpsområder (<i>avoid some runout areas</i>)	39 %	+1	11 %	−1
5. Unngå skredutsatte veier (<i>avoid avalanche-exposed roads</i>)	6 %	−1	75 %	+1
6. Kunne mye om snø for å vite hva jeg skal unngå (<i>know a lot about snow in order to know what to avoid</i>)	29 %	0	16 %	−1
7. Grave i snøen for å vite hva jeg skal unngå (<i>dig in the snow in order to know what to avoid</i>)	12 %	−1	6 %	−1
8. Vite mye om været siste to dager for å velge terreng (<i>know a lot about the weather the last two days in order to choose terrain</i>)	45 %	+1	13 %	−1
9. Forvente store lokale forskjeller (<i>expect large local variability</i>)	71 %	+1	16 %	−1

3 Results

In this chapter, we present the avalanche-related demographics of the user respondents (sections A and E), well-functioning and malfunctioning parts of the 2017 version of the avalanche warnings on Varsom.no, as perceived by the participants (Section B), the participants' evaluation of how well text, symbols and pictures assist the informational content in the warnings (data from Section C), the participants'

evaluations of how well different levels of complexity in the text persuade the informational content in the warnings (data from Section D), and test results for level of comprehension at different levels of complexity in the warning texts (also data from Section D).

Table 4. Contingency table of user respondents' experience (number of tours in avalanche terrain per year) versus competence.

Competence	Experience (tours in avalanche terrain per year)				N
	< 5	5–15	> 15		
0					
None	10 %	48 %	35 %	8 %	40
Competent, no course	6 %	23 %	41 %	30 %	81
Competent, course	0 %	6 %	39 %	55 %	121
Expert	0 %	5 %	14 %	82 %	22

3.1 Demographics

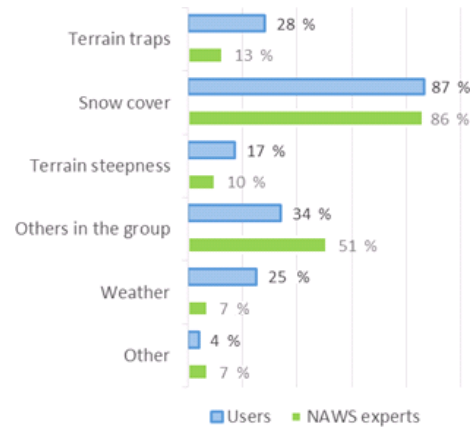
The statistics of the users with respect to competence, experience, activities and geography are listed below and in Table 4.

- 14 % of the user respondents had no or little avalanche knowledge (labelled “None” in Table 4), 27 % stated that they had avalanche-related competence but no formal training (“Competent, no course”), 48 % stated that they had avalanche-related competence and formal training (“Competent, course”), and 10 % were avalanche instructors or professionals (“Expert”).
- 82 % stated that they had used avalanche gear (e.g. avalanche beacon, shovel and probe) for several seasons, 7 % for one season only, and 11 % had never used this type of equipment.
- The majority of users stated that their main activity in avalanche terrain was alpine ski touring (66 %). Relatively many users also stated that they engaged in off-piste skiing (32 %), or Nordic mountain skiing (23 %), while relatively few said that they travel in avalanche terrain by foot (9 %), on a snowmobile (7 %), or on snow shoes (3 %). Three percent stated that they engage in other types of activities in avalanche terrain. Note that the users could chose multiple activities.
- Concerning the use of NAWS, 76 % of the users answered that they always use the avalanche warnings, 21 % that they use the warnings on a regular basis, and 3 % that they rarely read the forecast.

Many of the respondents have avalanche-related competence and formal training, and many use the avalanche warnings on a regular basis. This suggests that the sample of respondents could be biased towards a population with more avalanche expertise than average.

3.2 Avalanche warning

A total of 264 user respondents completed the questions in Section B. In this section, we asked the respondents to identify risk factors that they perceived difficult to manage or

**Figure 4.** Factors users and NAWS experts considered difficult to assess and manage in order to have a safe trip in avalanche terrain.

mitigate, parts of the avalanche warnings that they perceived difficult to understand, and important information perceived to be missing in the avalanche warnings. Key results from the 110 respondents in the NAWS expert survey are also presented in this chapter for comparison.

3.2.1 Avalanche risk factors considered difficult to assess and manage

In order to find out what the users consider to be most difficult to assess and manage, we asked “Which factors are most difficult to assess and manage in order to complete a safe trip?” The respondents could choose multiple factors. Available factors and results are shown in Fig. 4. The results show the following.

- The vast majority (87 %) of the users perceive the *snow cover* to be the single most difficult factor to assess and manage. This judgement does not depend on the respondent's experience or competence (χ^2 test, $p = 0.516$ and $p = 0.403$, respectively); 86 % of the NAWS experts considered this factor to be the most difficult factor.
- 34 % of the users perceive *other people in the group* to be the most problematic factor. More than every second NAWS expert (51 %) rated this as the most difficult one.
- Among the users, there is a relatively even distribution of individuals who perceive *terrain traps* (28 %) and *weather* (25 %) to constitute the other most problematic factors.
- Steepness is perceived as a problematic factor among relatively few respondents.



Figure 5. Factors the users and the NAWS experts considered most important in the avalanche warning on Varsom.no.

3.2.2 Avalanche risk factors considered most and least important

In order to find out what the users consider to be the *most important element in the warning*, we asked “Which elements in the avalanche warning are most important?” The respondents could choose multiple answers. Alternatives and results are presented in Fig. 5. The results show that the users perceive a relatively wide range of elements in the warning to be important.

- A majority of the users state that the *avalanche assessment* (69%), the *avalanche problems* (67%) and the *main message* (65%) constitute the three most important elements in the warning.
- About half of the users consider the *snow cover history* (56%) and the *danger level* (48%) to be important.
- Over a third of the users consider *snow and avalanche observations* (37%), *mountain weather* (39%) and *management advice* (42%) to be important.

We find no evidence that the elements chosen as most important depended on age, gender or experience (linear regression $R^2 = 0.022$, $p = 0.224$). The NAWS experts rated the *avalanche problems* as the most important factor (77%), followed by the *avalanche assessment* (62%), the *main message* (57%) and the *snow cover history* (55%). The *danger level* was considered most important by 39% only.

In order to find out what the users consider of *least importance or use*, we asked “Was anything of little use or importance? You may elaborate on the problem being format, content or other”. A total of 69 participants responded to this

question. Twenty of these provided positive or neutral comments. We summarize the critical feedback, and our interpretation of this feedback, below.

- Seven users stated that they found *the mountain weather to be superfluous*, and that they rather used the standard weather forecast. Thus, clarification in the difference between the weather forecast and the summary of the mountain weather, and the link between the mountain weather history and forecast, and the avalanche forecast, is recommended.
- Five users stated that the warning contained *too many, and complex details and information*. These users were mainly novices. This may imply that users with less skills and interest in the topic fail to get the key messages.
- However, another set of six users considered the level of detail to be *too low*. These users stated that the usefulness of the warning would be higher if it were less general, and if the forecast region was smaller. These answers point to the possibility that general forecasts for relatively large regions reduce the attention paid to the warnings.
- Three users found the *core zone sector diagram* to be problematic. More specifically, these users found it difficult to know whether dark sectors represent safe or unsafe regions. Although only three users commented on this, their feedback is important since it implies that some users of NAWS may chose the unsafe sector because they misunderstand the graphics. See also Sect. 3.2.3 for related results.
- Finally, four users found the *snow and avalanche observations* sometimes to be *too complicated* or described in *too difficult terms*.

3.2.3 Elements easily misunderstood or poorly communicated

A total of 95 users provided comments on whether the avalanche warning contains parts that are *easily misunderstood or poorly communicated*. Thirty of the comments were positive or neutral. We summarize the critical feedback, and our interpretation of the comments, below.

- Eleven users found the *core zone sector diagram* to be easily misunderstood. Like in the case of users who stated that the core sector diagram to be of little use, these users stated that they found it difficult to know which of the sectors (dark or light) that are most dangerous. Some users suggested to add a legend or use more or different colours. These findings corroborate the findings in Sect. 3.2.2.

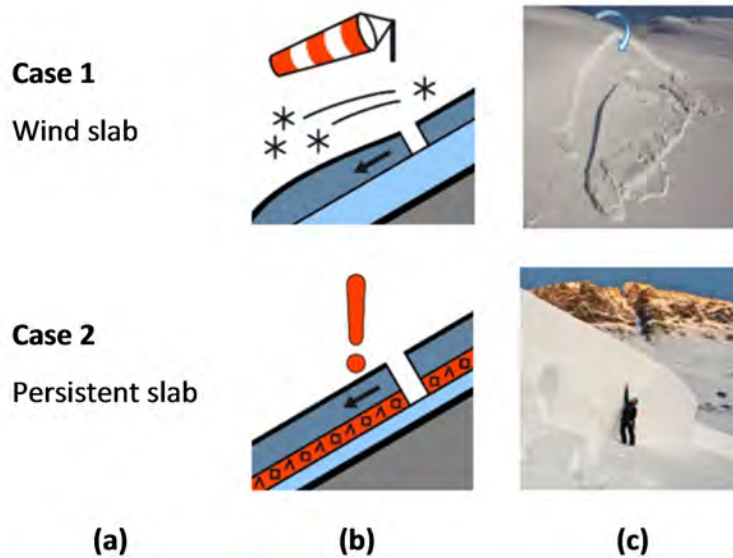


Figure 6. Test of what communicates the avalanche problem best in the avalanche warning: (a) text, (b) symbols or (c) pictures.

- Another 11 users perceived the regional warnings to provide *too little detail in terms of spatial or temporal variability*, and that the *forecasted regions were too large*. These findings corroborate the findings in Sect. 3.2.2.
- Eight users found it difficult to understand the *danger level*, in terms of the meaning and consequence of it for the user. This is important, because if users do not understand the meaning of the danger level, they are poorly equipped to manage their risk exposure.
- Finally, six users stated that the large amount of information provided in the warning made it difficult, especially for beginners, to decipher the key message. This corroborates the findings reported in Sect. 3.2.2, where five users stated that the warning contained too much detail and information.

The answers from the NAWS expert survey suggest that experts perceive similar factors to be as problematic as users do: i.e. the *core sector and elevation diagrams, spatial and temporal variability, danger level, and uncertainty*. However, the NAWS experts also pointed to a few problematic factors not mentioned by the users: *avalanche size* (especially the name “small” used for size 2), *probability* and *distribution*. Note that the EAWS is changing the denominations used for avalanche sizes during 2018, which will resolve the problem with communicating size 2 avalanches.

3.2.4 Missing information and features

In the final part of Section B, we asked the respondents to identify missing information in the avalanche warning. Sixty-seven respondents provided comments. About 20 of

these stated that no important information was missing. The elements asked for by the remaining 47 participants were the following:

- observed weather and snow, and links to more detailed observations;
- ATEs recommendations (Avalanche Terrain Exposure Scale is a method for classifying the degree of terrain avalanche-exposure, Statham et al., 2006);
- advice connected to competence levels, and
- more detailed warnings/information. Better visualization of important weak layers (depth, type, etc.).

We also asked the participants whether some information or features are missing in the RegObs application. Eighty-one users responded to this question, of which about 35 responded that they did not use the application or were indifferent. The users asked for the following to be included in future releases:

- weather data,
- a possibility to enter and record snow profiles,
- a possibility to read the avalanche warning (at least the danger level and avalanche problems) in the application,
- an opportunity to track trips,
- a more user-friendly interface,
- access to avalanches and avalanche paths,
- information about actual elevation in relation to the avalanche problem elevation range, and

Table 5. Results from the test of what communicates the avalanche problem best in the avalanche warning.

Text	Symbol	Picture	Rating
46 %	51 %	38 %	Good
40 %	38 %	36 %	OK
14 %	11 %	25 %	Poor

- easy access to the snow cover history and relevant recent snow profiles nearby.

Several of these features are being implemented by the time of publication of this study.

The results from the NAWS expert survey suggested that these pieces of information in demand:

- more precise description of where in the region or terrain the avalanche problem is expected, and where the danger level is expected to be lower, and
- a better description of the uncertainty and local variability.

3.3 Testing of text versus symbols or pictures

In section C, we asked the respondents to rate how well text, icons, and pictures communicate the avalanche problem on a scale from 1 = poor, to 3 = good. Each respondent evaluated two types of avalanche problems: a wind slab, and a persistent slab (see Fig. 6). A total of 222 user respondents completed this section of the survey.

The results show that users preferred text and symbols to pictures (Table 5): 89 % rated the new EAWS symbols as good or OK. The users were familiar with the names of the avalanche problems, which have been presented as text on Varsom.no during the previous three seasons. The users were not familiar with the symbols, as they were introduced at Varsom.no for the 2017/2018 season after being introduced as an EAWS standard in June 2017 (EAWS, 2017b). Pictures have not been used in the warning on Varsom.no, but a few users may have seen the pictures in the avalanche school at Varsom.no. Notably, we found that the symbols were rated more positively the more experienced a respondent was: $\chi^2_{203} = 15.26$, $p = 0.018$. The text and pictures were rated equally irrespective of one's experience: $p = 0.338$ and $p = 0.543$, respectively.

3.4 Testing of comprehension of the two scenarios

A total of 177 user respondents completed the test for comprehension in Section D by responding to one of the four alternatives for each of the two scenarios. To recap, we asked the respondents to (1) rate how well they perceived the avalanche danger to be communicated, (2) what the most important behavioural implications of the warning were, and

(3) what advice they would give to others based on the warning message. We measured how well the danger was communicated in the warning on a scale from 1 to 10. Of those who provided answers to this question, 21 % gave a rating of 10, and 56 % a rating of 8 or higher. Only 14 % gave a rating of 4 or lower. Mean ratings for the two scenarios (danger level 2 and level 4) and for each of the four alternatives are presented in Fig. 7 below (left column). Figure 7 also depicts the comprehension scores (right column). Higher scores indicate a higher match between the behavioural implications chosen by the users and the NAWS experts. For the danger level 2 scenario the minimum score is -4 and the maximum score is $+4$, while scores for the danger level 4 scenario range from -6 to $+3$.

We next compared the user ranking and comprehension score in more detail, by (a) comparing the comprehension score to a score of 0 and (b) investigating whether user ranking or comprehension differs between the four alternatives with ANCOVAs where a user's experience was a covariate. For statistical analysis we used JASP (2018).

3.4.1 Danger level 2 wind slab scenario

For the danger level 2 wind slab scenario, the average user ranking of the four alternatives ranged from 5.1 to 7.4. The four alternatives were rated differently: $F(3, 172) = 10.124$, $p < 0.001$, $\eta^2 = 0.149$. Alternative 2, i.e. an avalanche problem with technical information and advice, was rated highest, and alternative 1, a danger level with an explanation, least informative. A post hoc Tukey test confirmed it: alternative 1 was rated lower than the other three alternatives ($p's < 0.001$, smallest effect size Cohen's $d = 0.814$). A user's competence had no effect on the ranking of the alternatives: $F(1, 172) = 1.966$, $p = 0.163$, $\eta^2 = 0.010$. Experience was also non-significant; a user's experience had no effect on the ranking of the alternatives: $F(1, 172) = 0.469$, $p = 0.494$, $\eta^2 = 0.002$.

Comprehension was good, with all four alternatives yielding overall positive scores, i.e. one-sampled tests for all four alternatives were significantly different from a score of 0 (alternative 1: $p = 0.015$, alternatives 2–4: $p's < 0.001$). Still, the comprehension scores were different for the four alternatives: $F(3, 172) = 8.188$, $p < 0.001$, $\eta^2 = 0.120$. Alternative 1, a danger level with an explanation, had the lowest comprehension score and was significantly different from the other three alternatives; post hoc Tukey tests had the smallest $p = 0.021$ and the smallest effect size Cohen's $d = 0.541$. Notably, the higher the competence the better the comprehension was: $F(1, 172) = 7.777$, $p = 0.006$, $\eta^2 = 0.038$. Finally, there was a positive correlation between user ranking and comprehension: $\rho = 0.2$, $p = 0.008$, 95 % CI [.054; .337].

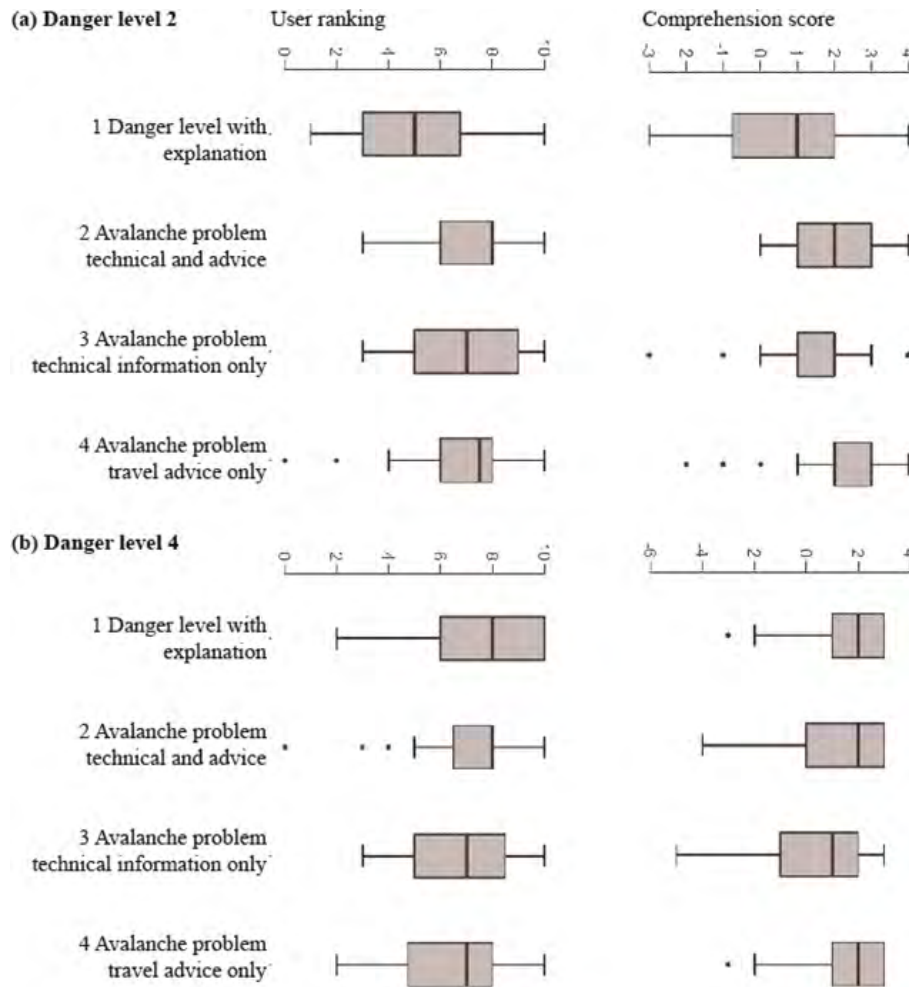


Figure 7. (a) User rating (left) and comprehension score (right) for the level 2 wind slab scenario; (b) user rating and comprehension score for the level 2 wet slab scenario.

3.4.2 Danger level 4 wet slab scenario

For the danger level 4 wet slab scenario, the average user ranking of the four alternatives ranged from 6.7 to 7.7. All alternatives (danger level, avalanche problem) were ranked high, and there was no statistically significant difference: $F(3, 172) = 1.787$, $p = 0.151$, $\eta^2 = 0.030$. Also, a user's experience and competence did not influence the ranking (both F 's < 1).

Comprehension was good, with all four presentations of the scenario yielding overall positive scores. All but alternative 3 had a significant positive score (alternative 3 only marginally: $p = 0.065$, Cohen's $d = 0.262$). The four alternatives did differ: $F(3, 173) = 4.188$, $p = 0.007$, $\eta^2 = 0.067$. Alternative 3, an avalanche problem with technical information only, received a significantly lower comprehension score than alternative 1 (post hoc Tukey: $p = 0.037$, Cohen's $d = 0.607$), and alternative 4 (post hoc Tukey $p = 0.006$, Cohen's $d = 0.763$). A user's competence had no effect on

comprehension: $F(1, 172) = 0.93$, $p = 0.336$, $\eta^2 = 0.005$. There was also no relationship between user ranking and comprehension: $\rho = -0.095$, $p = 0.207$.

3.4.3 Comparison

The results show that for the danger level 2 scenario, the three alternatives with the avalanche problems communicate more effectively than the one with the danger level. The user ranking and the calculated comprehension score provide consistent results. For the danger level 4 scenario, on the other hand, the alternatives with the danger level and avalanche problem with travel advice score higher than the two other alternatives. The difference is clearer for the calculated comprehension score than for the user ranking. The alternative with the avalanche problem and technical details seems to communicate least effectively however, it is also possible that users become too careful/conservative and rate factors as important that experts do not, and hence receive a lower score.

4 Discussion

The purpose of this paper was to evaluate how well the avalanche warnings, as provided by NAWS, are communicated to the public, and whether some modes of presenting the warnings are more effective than others in communicating the *intended* message. We discuss our main findings below: firstly, we discuss the user results that are reported in Sect. 3.2 (avalanche warning); secondly we discuss the results reported in Sect. 3.3 (modes of communication: text versus symbols and pictures) and finally the results from the test of comprehension reported in Sect. 3.4.

4.1 The avalanche warning

Our survey responses suggest that users find it most difficult to assess and manage the *snow cover*, but that relatively many individuals also find it challenging to manage *group dynamics* and *terrain traps*. The fact that so many (both experts, experienced users and novices) struggle with an evaluation of the snow cover and its impact on the avalanche hazard is not surprising. The snow cover is difficult to assess and manage, it can vary considerably over both short time periods and distances (Schweizer et al., 2008). It is created by a complex and dynamic interaction between the atmosphere, the old snow cover, and the ground, and the development of the snow cover over time may create complex structures and properties. Visual surface clues are few and information on the internal structure and properties hard to come by. The difficulty in assessing and managing the snow cover is reflected in what users perceive as most important in the avalanche warning: the *avalanche assessment*, the *avalanche problems* and the *main message*.

A well-functioning avalanche warning needs to translate the complex dynamics and characteristics of the snow cover and avalanche hazard into a clear message that novices and experts find useful and can translate into behavioural implications. However, although the responses to our survey questions suggest that most users demand this type of information, the responses also show that it is challenging to create a warning that will fit all needs. While some users would like to see more detailed information on the type of avalanche problems and geographical distribution of these problems, the characteristics of the snow cover (including spatial and temporal variability), weather patterns, and estimates of uncertainty in the forecast, other users state that the amount of information and detail currently available in the warning is already too high and complex, and that it makes them confused.

Today, the Norwegian avalanche warning describes the avalanche hazard using both symbolic representations, a summary of the behavioural implications, and more lengthy descriptions of the avalanche problem, the snow cover, and the mountain weather. In addition, users have access to snow observations via RegObs. The symbolic representation of the

avalanche danger and main message is currently presented at the top of the page, while more detailed information is available lower down or to the side.

Our interpretation of the responses given in the survey is that the avalanche warning should maintain its current structure, with easy-to-grasp information for all users (novices as well as experts) at the top level of the warning, and more detailed and complete information for advanced users, e.g. information about the type of avalanche problem, character, timing, geographical distribution, and reliability of observations, at a lower level. On the other hand, most NAWS experts (77 %) and users (67 %) rated the avalanche problem as the most important element of the warning. This, in combination with several users saying that there is too much and too complex a text (i.e. redundancy), suggests that the avalanche problems should be communicated high up in the warning. A more compact presentation with less information would strengthen the communication efficiency, in particular if the overlap with the avalanche danger assessment text is reduced. We also see several other areas for improvement. (1) The *danger level* was considered important by many, but by less than 50 % of the users. This may suggest that this element may be better off at a less pronounced place on the page. (2) Many individuals find it difficult to interpret the *core sector* and *elevation diagrams*, mainly in terms of identifying safe and unsafe sectors. To remedy this problem, it may prove beneficial to show the danger level and/or avalanche problem in two to three different elevation bands, as is done by several European and Canadian AWS', or to use bold red colours (at the risk of confusing it with the red colour used for danger level 4) and clearer fonts. (3) Information on weather is at times repeated in several places in the avalanche warning, e.g. in the weather forecast, the avalanche assessment, the avalanche problems and the snow cover discussion. To improve clarity and readability, it may prove beneficial to remove redundant information about the weather. (4) To increase the usefulness of snow observations, the interface of RegObs may need revision.

4.2 Modes of communication: text versus symbols and pictures

Our empirical analysis shows that most respondents prefer symbols and text to pictures. The preference for text messages may partly be explained by the fact that users have become accustomed to this mode of communication: NAWS has presented the avalanche warnings using text during its 5 years of operation. Another potential explanation is that the names of the avalanche problems are easily communicated verbally – in interviews in the media, during avalanche courses and when discussing the avalanche danger before and during trips. Even though symbols are efficient, text labels are very useful. The EAWS symbols were new to Norwegian users, and the positive rating of these supports the decision to introduce these symbols as a standard in Europe.

Unfortunately, it was beyond the scope of this study to test whether the wording of text messages and the symbolic representation of avalanche problems are optimal for communicating the intended message. To do this, more advanced testing is needed.

The relatively low rating of pictures may be explained by the choice of certain pictures, or by the amount of detail in them. Pictures are bound to be taken at a certain location, under certain circumstances, and almost always contain some amount of irrelevant information. As a consequence, the main message may become blurred, and some users may feel that the snow or landscape is not representative of the avalanche forecast or region. More tests of pictures, or even video, could be carried out to explore whether these otherwise very effective media could be used to communicate the avalanche danger, perhaps as a complement to the other parts of the forecast. NAWS has posted pictures and videos of the current situation a number of times on Facebook, and especially the videos have had a large impact measured by the number of views, likes, comments and shares. This suggests that a more elaborate study on the effect of pictures and videos should be carried out. However, the costs of obtaining relevant quality video and pictures may outweigh the benefits.

4.3 Modes of communication: comprehension

We evaluated comprehension of the communicated avalanche warnings by the use of two methods: we first asked respondents to rate how well the avalanche hazard and the associated behavioural implications were communicated, and thereafter tested whether different modes of communication resulted in different “comprehension scores”. All participants evaluated a danger level 2 scenario (wind slab) and a danger 4 scenario (wet slab). In each of these scenarios, the participants were randomly exposed to one out of four alternative descriptions of the avalanche hazard and asked to choose the behavioural implications associated with the warning. The comprehension score was based on a comparison between the choices made by users and a template constructed from the answers made by a panel of NAWS experts.

Our empirical analysis of the subjective rating of the avalanche warnings shows that most users perceive Varso.no to communicate the avalanche hazard in a good way: 51 % of the users rated the communication of the danger in the level 4 scenarios as 8 or higher, on a scale from 1 to 10 (41 % in the level 2 scenario). These results are consistent with previous studies on user satisfaction (Kosberg et al., 2013; Barfod et al., 2014, 2015) and the conclusions in a recent evaluation of NAWS (Hisdal et al., 2017).

The rating of the different alternatives depends on the scenario. For the level 2 (wind slab) scenario, alternative 2 (avalanche problem and technical information and advice) received the highest rating, slightly higher than alternative 4

(avalanche problem and advice). Alternative 1 (danger level) was rated the lowest. For the level 4 (wet slab) scenario, it was alternative 1 that received the highest rating but this was not significantly different from any of the other alternatives. These results suggest that the users perceive that they need more detailed information than just a danger level when given a danger level 2, but are highly satisfied with knowing the danger level if it is 4. Notably, for danger level 2 a user’s competence mattered when it came to the rating of the alternatives, but not for danger level 4. This suggests that the value of more detailed information about the avalanche problem increase as the user’s competence level increase. Level 4 might be a cut-off for most, in terms of making the decision not to enter avalanche terrain. The avalanche-related demographics data from the user respondents (Section A and E) showed that the more competent the users, the more tours they undertake in avalanche terrain. However, quite a few of those without competence or courses are also active ski touring. Most respondents assessed themselves as being competent. Hallandvik et al. (2017) showed that novices assessed the terrain for a specific site as less complex than experts, they weighted information in the avalanche forecast differently, and used different strategies to gather information about the snowpack on a trip. Thus experience and competence matter to a certain degree when communicating avalanche danger. In our study, the sample of respondents may be biased towards experienced and interested users, which may somehow affect the results (e.g. Haegeli et al., 2012).

Our results from the test of the level of comprehension for the level 2 scenario (wind slab) are largely consistent with participants’ subjective evaluations: participants score significantly lower on the comprehension score if the only information available is a danger level with a standard explanation (alternative 1). We therefore argue that a simple danger level is not enough to convey the intended warning message on lower danger levels. At this level, the users consider how to travel in avalanche terrain, rather than whether or not to enter avalanche terrain. Rather, in this situation the warning should present the avalanche problem with a reasonable level of detail. Our results do not provide a clear answer to the question of which details are most important in order to communicate the message; indeed, all three alternatives yielded a higher comprehension score than alternative 1.

The results from the level 4 scenario (wet slab) are markedly different from the level 2 scenario, in terms of both comprehension scores and the match between objective comprehension and subjective evaluations. In contrast to the level 2 scenario, users rated all alternatives equally. However, in this scenario, the comprehension score was significantly *lower* for alternative 3 than it was for alternatives 1 and 4. In other words, leaving out the advice and explanation resulted in a lower comprehension. Note though that all four alternatives yielded positive scores: most users did select the same factors as the experts. One possible explanation

for the observed lower comprehension score for alternative 3 is that the technical information caused confusion rather than helped the respondents.

Based on the results of our empirical analysis, our recommendation is that NAWS should carefully assess the importance and priority of details presented with the avalanche problem in order to shorten and simplify the communication of the danger to the different user groups. It is important to consider the redundancy of information. If two or three avalanche problems are presented in the warning, the redundancy between the details in the problems as well as the main message and danger assessment may be considerable. NAWS should consider how to normalize the avalanche warning, in order to avoid repeating the same information several times. Our results also points to the importance of communicating the avalanche problems at a high level in the warning, especially for warnings on lower danger levels. However, both the avalanche situation and the snow cover may be very complex across the warning region and forecasting period. The NAWS warning regions are about 20 times the European average (Engeset, 2013; Techel et al., 2018), and some have rather complex topography and weather patterns. Simplicity may not always be achievable without leaving out important information for the users.

There are several factors that may have affected the results presented in this study, and we would like to linger around them. First, it is important to note that this study targeted recreational users, and not preparedness authority personnel. The needs of novice, advanced, and professional users are likely to differ. While simple symbols and messages are likely beneficial for individuals with less avalanche knowledge, technical details can be of great use for advanced users. Properties such as sector, elevation, size and probability of release are useful when considering which roads or residential areas are exposed to the avalanche danger. We therefore recommend that a more detailed study should be carried out, in order to investigate what is effective to communicate to preparedness users. Second, the Norwegian users were only recently introduced to a national avalanche warning system. This implies that many users have been in the process of acquiring knowledge about how to assess avalanche danger during the period from 2013 to 2018. Other than the avalanche warnings provided by NAWS, few sources for assessing the avalanche danger are available in Norway. Most avalanche courses frequently use the avalanche warnings and avalanche educational resources on Varsom.no. Finally, we only tested a limited set of alternative communication modes to the participants. To fully evaluate how to optimally design the avalanche warning, tests with more variations and scenarios are needed.

5 Conclusions and recommendations

In this study, we investigated how well users perceive the avalanche warnings on Varsom.no (<http://www.varsom.no>, last access: 9 September 2018) to be communicated, and whether different modes of communication affect the level of comprehension of the hazard at hand. We also identified elements in the avalanche warnings that users perceive to be of greater or lesser importance, easily misunderstood, or missing.

Based on our empirical analysis of the data, we make the following conclusions and recommendations.

1. *Redesign core zone and elevation graphics/text.* Problem: participants found it difficult to understand whether the avalanche problems were present or absent in coloured sectors. Possible solution: use colours, bolder text and better symbols, and show the danger level and/or avalanche problem in two to three different elevation bands, as is done by several European AWS' and in Canada.
2. *Less is more.* Problem: the amount of text and detail in the warning reduced the motivation to read the warning and made it more difficult for the user to pick up the main message. Possible solution: minimize repetitive information and reduce complexity.
3. *Local information matters.* Problem: the avalanche warnings are produced for relatively large geographical areas with big spatial variations in the snow cover. Possible solution: use maps to show the parts of the region (subregions or elevation intervals) that are most affected by the avalanche problem(s), or where the avalanche danger is expected to be one value higher or lower than the rest of the region. Maps could show which parts are most affected, by showing the properties creating the avalanche problems, e.g. heavy precipitation, wind, or temperature. NAWS could use sub-regions as a way to provide better information in the textual analysis. NAWS will probably not have information with the required detail to present higher-resolution maps of danger level or avalanche problems yet. Another way could be to present local weather history, and/or snow observations from automatic stations, or to present the snow history by visualizing some manual snow observations as time series.
4. *We need to teach snow dynamics.* Problem: a very large share of respondents state that they find it most difficult to assess and manage the snow cover. Possible solution: present the avalanche problem, snow cover analysis and avalanche danger assessment in a more systematic and pedagogical manner in order to improve the competence of the users. It should be noted that even the NAWS experts considered the snow cover to be the most difficult

factor, suggesting that it is complex to manage for users at all levels.

5. *We need to teach people dynamics and terrain traps.* Problem: a large share find it difficult to manage others in the group. Many also find terrain traps problematic. Possible solution: use the “avalanche school” to educate users about terrain traps and talk about group dynamics to help users make better choices about whom they choose to recreate with in avalanche terrain.
6. *Avalanche problem is important.* Problem: the avalanche danger level is not enough for making decisions in avalanche terrain, more detailed information is needed. Possible solution: promote the avalanche problem, especially at danger levels 2 and 3, which also are the conditions most fatalities occur. Streamline the presentation of the avalanche problem according to danger level and reduce overlap with the avalanche danger assessment in order to reduce the complexity for users. Reduce the amount of information to users at higher danger levels. The danger level was rated as important, but somewhat difficult to understand. It is a simple numeric value, but is determined from relatively complex and subjective factors, and is probably difficult for users to understand and use.
7. *Keep the EAWS symbols.* The users considered the new EAWS standard icons for the avalanche problems to communicate the danger well, although the users were not familiar with the icons.

In conclusion, our study has confirmed that the communication of the avalanche danger on Varsom.no is perceived to be effective by the users. The results of the testing of the effectiveness of different alternatives for communication of level 2 and level 4 avalanche danger suggested that the avalanche problems communicated more effectively than the danger level at lower danger levels. At the higher danger levels, no significant difference was found between the alternatives. The results suggest that a simple danger level is not enough to convey the intended warning message on lower danger levels; rather, the warning should present the avalanche problem with a reasonable level of detail. At higher danger levels, the results suggest that leaving out the advice and explanation resulted in lower comprehension. For danger level 2 a user’s competence mattered when it came to the rating of the alternatives, but not for danger level 4. Many users (67 %) and most NAWS experts (77 %) rated the avalanche problem as the most important element of the warning.

Based on the findings in this study, NAWS redesigned the avalanche warning on Varsom.no: the communication of the core sectors was improved (displayed in red signal colour rather than vague grey), a location search function was added, the display of avalanche problems was moved up to just below the main message, the redundancy in infor-

mation between the avalanche problem, snow cover analysis and avalanche danger assessment was reduced, the region map was relocated down to the bottom of the page and the mountain weather and snow cover analysis was restructured.

Norwegian users, experts and avalanche warnings were used in this study, but we believe the methods and results are important to the wider scientific community and AWS’ in other countries. The building blocks and communication techniques of the avalanche warnings on Varsom.no follow the standards of EAWS, as Varsom.no and NAWS were developed in collaboration with a number of AWS’ in Europe and North America.

Our study sheds light on how effectively key information is communicated in avalanche warnings. However, we recommend more studies on communication and impact of avalanche warnings, including in-the-field testing, testing of the use of avalanche problems with regards to people and terrain choices, and further development of methods for quantifying the effectiveness of such communication.

Data availability. The online survey stated that the data were to be used by the project only and that they would be treated confidentially. Thus, the data were not deposited in a public data repository.

Author contributions. RVE designed the study, carried out part the data analysis and interpretation of results and wrote the manuscript. GP contributed to the study design, the statistical data analysis and the writing of the manuscript. ML and AM contributed to the study design, the interpretation of results and the writing of the manuscript. AH contributed to the study design and the writing of the manuscript.

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Should I Judge Safety or Danger? Perceived Risk Depends on the Question Frame

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Abstract

Linguistic polarity is a natural characteristic of judgments: Is that situation safe/dangerous? How difficult/easy was the task? Is that politician honest/dishonest? Across six studies ($N = 1599$), we tested how the qualitative frame of the question eliciting a risk judgment influenced risk perception and behavior intention. Using a series of hypothetical scenarios of skiing in avalanche terrain, experienced backcountry skiers judged either *how safe* or *how dangerous* each scenario was and indicated whether they would ski the scenario. Phrasing risk judgments in terms of safety elicited lower judged safety values, which in turn resulted in a lower likelihood of intending to ski the slope. The frame “safe” did not evoke a more positive assessment than the frame “danger” as might be expected under a valence-consistent or communication-driven framing effect. This seemingly paradoxical direction of the effect suggests that the question frame directed attention in a way that guided selective information sampling. Uncertainty was not required for this effect as it was observed when judging objectively safe, uncertain, and dangerous scenarios. These findings advance our theoretical understanding of framing effects and can inform the development of practices that harness question framing for applied risk perception and communication.

Keywords: Framing effect; risk perception; judgment and decision making; attention; avalanche terrain

Public Significance Statement

This study demonstrates that risk judgments framed in terms of safety (*How safe is it?*) result in more cautious, conservative judgments than when framed in terms of danger (*How dangerous is it?*), irrespective of the objective risk of the judged object. These findings advance our understanding of the framing effect while illustrating its particular relevance for applied risk perception practices and for public hazard forecasting and information communication strategies.

Should I Judge Safety or Danger? Perceived Risk Depends on the Question Frame

Framing is a ubiquitous psychological phenomenon that holds much promise for applied risk communication and risk perception. A wealth of empirical findings have shown that the way in which a problem, situation, object, event, or goal is described affects how people respond to or evaluate it (for reviews see e.g., Kühberger, 1998, 2017; Levin et al., 1998; Maule & Villejoubert, 2007; Piñon & Gambará, 2005). Framing effects are traditionally regarded as a deviation from rational behavior (Kahneman & Tversky, 1984; Tversky & Kahneman, 1981). Recognizing the potential problems that framing effects can cause, researchers have investigated numerous methods for debiasing or diminishing framing effects (Almashat et al., 2008; Garcia-Retamero & Dhimi, 2013; Sieck & Yates, 1997; Simon et al., 2004). Yet not all instances of framing effects are considered problematic, harmful, or disadvantageous. The purposeful use of framing to promote specific judgments and decisions is an established practice in several fields such as media and communications (Block & Keller, 1995; Chong & Druckman, 2007; Scheufele & Tewksbury, 2007) and marketing (Biswas, 2009; Biswas & Grau, 2008; Levin & Gaeth, 1988). Might the framing effect be similarly harnessed to boost people's natural decision making competencies in order to ensure better, safer risk perceptions? If so, the framing effect has the potential for a real and tangible impact on how people judge risk and, ultimately, how they behave under risky conditions.

In this article, we employ decision making in avalanche terrain as an exemplary case for investigating risk judgments and behavior in domains of applied risk perception and risk communication. Decision making in avalanche terrain represents a paradigmatic case of applied risk judgments and decisions. Avalanche terrain is a highly complex and uncertain decision environment in which judgment errors can result in severe injury or death. Moreover, it is an environment where poor decisions are frequently marked by invalid feedback (cf. Hogarth et al.,

2015). A mismatch between perceived risk and reality can therefore be present for even the most experienced decision makers. Nonetheless, skiing in avalanche terrain is an increasingly popular but largely unregulated activity in which people voluntarily engage, most often for purely recreational purposes. Decision making in avalanche terrain provides a paradigmatic case for investigating decisions under real-life uncertainty among an experienced, highly motivated population. Yet the relevance of this research is not limited to backcountry skiing. Frame selection and the strategic phrasing of risk judgments are relevant for a range of disciplines and contexts including police, fire and other emergency services, military operations, the finance sector, work in volatile natural environments such as fisheries, illicit activities such as recreational drug use, and for medical diagnoses and treatment decisions. Decision making in avalanche terrain offers a convenient exemplary case for investigating the effect of framing on risk perception under varying degrees of uncertainty.

One type of framing that appears to be highly relevant for applied risk perception and risk communication is the question frame. Judgments are commonly framed in terms of a single dimension of an integral qualitative attribute of what is judged. For example, “How *bad* is the situation?”, “How *expensive* is a product?”, or “How *difficult* is an activity?” (as opposed to how good, inexpensive, or easy). Polarity is a natural characteristic of language that constrains and thereby defines the formulation of many judgments to a single dimension of a bipolar attribute (Hilton, 2011). Decision makers therefore naturally employ a single dimension of a qualitative reference such as *safe* or *dangerous* to frame a risk judgment.

Using hypothetical scenarios of backcountry skiing in avalanche terrain across six studies ($N = 1599$), we examined how recreational backcountry skiers evaluated these scenarios when asked to judge *how safe* versus *how dangerous* they are. We also examined how the question frames influenced participants’ decision to ski the scenarios. We tested the effect of the question

frames on risk perception and behavior intention when judging scenarios of different objective risk levels: scenarios of uncertain risk (Studies 1-6), safe scenarios (Studies 5-6), and dangerous scenarios (Studies 5-6). Based on the existing framing literature, we can expect to find an effect when framing a risk judgment in terms of safety or danger. Beyond that, however, prior research has not established the direction of that question framing effect, the prevalence of that effect under different conditions of objective risk, or the association of that framing effect with behavior intention. How does a qualitative reference frame influence perceived risk? Which of the two frames – safe or dangerous – evokes a more conservative, cautious risk judgment? Is uncertainty a requirement for an effect or does it persist in the face of credible evidence of safety or danger? How does the question framing effect influence behavior, which is ultimately what exposes a person to risk? Different accounts of the cognitive processes underlying framing effects make conflicting predictions about the direction and prevalence of an effect evoked by a question frame. These issues must be resolved in order to determine if it might be possible to harness question framing to promote safer risk judgments and decisions.

Divergent Accounts of Framing and the Direction of the Predicted Effect

Framing effects are diverse and inspire broad theoretical and applied interest in psychology, economics, political science, health sciences, and beyond. Consequently, a variety of heterogeneous phenomena that evoke differing cognitive processes and divergent effects are classified as framing (for reviews, see e.g., Chong & Druckman, 2007; Kühberger, 1998, 2017; Levin et al., 1998; Maule & Villejoubert, 2007). Research on framing in psychology and economics has primarily focused on situations in which different but logically equivalent descriptions lead to different preferences or evaluations, highlighting a violation of the economic principle of invariance (e.g., Tversky & Kahneman, 1981). For example, evaluations tend to be more favorable when a product is described as 90% fat-free than when described as containing

10% fat (e.g., Levin, 1987). This research has traditionally used risky choice framing in which the probabilities of the choice options are differently described (e.g., the classic “Asian disease problem”; Tversky & Kahneman, 1981), and attribute framing in which a single attribute of the target of judgment is differently described (Levin et al., 1998; Piñon & Gambará, 2005).

Manipulating the qualitative attribute that frames the question eliciting a judgment (i.e., question framing) has received much less attention in this line of research and has produced mixed results (see e.g., Payne et al., 2013; Comerford & Robinson, 2017).

Research in the fields of political science and health sciences have applied a broader conception of framing in which emphasis on different aspects of an issue leads to different opinions, without necessitating logical equivalence between frames (e.g., Cacciatoe et al., 2016; Chong & Druckman, 2007; Druckman, 2001; Bui et al., 2015; Nelson et al., 1997). For example, when asked about government funded financial assistance for people in need, political opinions tend to be more favorable toward government spending if preempted with an emphasis on humanitarian aspects rather than government expenditures (Druckmann, 2001). This broader conception of framing effects is also relevant to survey studies (see Bruine de Bruin, 2011), in which questions with presumed synonyms can elicit inconsistent responses (e.g., Bruine de Bruin et al., 2012) and questions with presumed antonyms can fail to communicate polar opposites (e.g., Holleman, 2006).

The cognitive processes that a frame activates and the direction of the resulting framing effect likely depend on the form and domain in which the frame is achieved. Consequently, several cognitive, communicative, and attentional processes have been proposed for framing effects achieved inside and outside the lab (for a review, see Keren, 2011). These different accounts of framing make somewhat conflicting predictions about how the question frame we tested might affect people’s judgment. Does a question about “safety” evoke a more reassuring

assessment than a question about “danger” because it triggers a positive connotation or conveys the assumption of safety in the question? Alternatively, does a question about “safety” direct a decision maker’s attention to the sparsity of evidence of safety under conditions of uncertainty, thereby prompting a more conservative evaluation? These different theoretical accounts of framing were established and predominantly tested based on risky choice framing and attribute framing research. The extent to which they describe and can predict a question framing effect is presently unclear (see Comerford & Robinson, 2017). By testing the direction of the framing effect evoked when risk judgments are framed in terms of safety and danger, we can infer the cognitive processes that are activated. Because the success of any effort to strategically harness framing in applied contexts depends on correctly matching the type of frame – and the cognitive process that it activates – with the objective for its application, we next review these different accounts of framing in the context of our study.

Valence-driven account of framing effects

One prominent cognitive account posits that framing information in either a positive or a negative way evokes a *valence-consistent* association that influences the selection and encoding of information about the target(s) of judgment (for reviews, Keren, 2011; Levin et al., 1998; Piñon & Gambará, 2005; Teigen, 2015). For example, positively framing an action (75% chance of success) evokes positive associations resulting in more favorable judgments of that action than does negatively framing the same action (25% chance of failure), despite the two frames being logically equivalent. Investigating the valence account of framing in the context of question frames, Payne and colleagues (2013) found that life expectancy predictions were longer when judging the probability to “*live to*” a certain age than when judging the probability to “*die by*” that age. Subjective probability judgments about longevity and verbal protocols both indicated that the “*live to*” frame evoked more positive thoughts than the “*die by*” frame did. For our

context of risk judgments, assuming that the quality *safe* has a positive valence and the quality *dangerous* has a negative valence (Hedger et al., 2016), then according to the valence account of framing, a risk judgment phrased as *How safe is it?* should evoke positive associations that may result in higher judged safety than a risk judgment phrased as *How dangerous is it?* However, other empirical findings cast doubt on whether valence consistent associations adequately account for question framing effects. Although Comerford and Robinson (2017) replicated the results of Payne et al (2013), they also found that the response format influenced the direction of the question framing effect and, we can assume, the underlying cognitive processes. When decision makers reported life expectancy as a point estimate in response to a framed statement “*I expect to live to/die by age...*”, life expectancy was longer under the “*die by*” frame. These surprisingly contradictory results highlight the continuing uncertainty about the cognitive processes activated by attribute framing of questions and the direction of the evoked effect.

Communicative accounts of framing effects

Another influential account of framing holds that the pragmatics of language and communication contribute to framing effects (Hilton, 2011; McKenzie, 2004; McKenzie & Nelson, 2003; Sher & McKenzie, 2006). A frame is typically selected by a source (i.e., a speaker) communicating information about the target(s) of judgment. Importantly, the speaker’s choice of frame and the listener’s inferences about that choice are not arbitrary. Consequently, the choice of frame “leaks” implicit information about a target beyond what is explicitly stated. In this way, logically equivalent frames might not be informationally equivalent because the choice of frame conveys judgment-relevant information, notably the communicator’s perspective on the target of judgment. Differently framed questions in survey research are typically also understood according to such a communicative theoretical framework that regards the interaction between researcher and survey respondent as a form of communication subject to the rules of everyday

conversation (Grice, 1975). In our study, the differently framed question that elicits the risk judgment could be interpreted as leaking different information about the communicator's (i.e., the researcher's) perception of the target of judgment. When asked the question "*How safe is it?*" the decision maker may plausibly assume that the communicator asking the question perceives the target of judgment to be safe. Otherwise, the communicator would have asked "*How dangerous is it?*" if the target was perceived to be dangerous. Although the cognitive process believed to underlie this framing effect differs from the valence account, the communication account of framing might similarly predict that the term *safe* in the question would elicit judgments of higher safety than would the term *dangerous* in the question.

Attentional accounts of framing

A final account of framing highlights attentional processes. These assert that a frame cues the cognitive system to direct attentional resources toward a certain perspective on the target(s) of judgment while suppressing attention toward alternative perspectives (e.g., Keren, 2011; Teigen, 2015). Judging a target involves cognitive processes that operate in relative terms. All judgments are relative to a reference that is the focus of attention, and the nature and location of that reference influence the judgment (Keren, 2011). Research in psychology using numerically framed single-bound probability judgments found that a frame defines a descriptive state (e.g., more than 85%) as the provisional reference point for the judgment (Hohle & Teigen, 2018; Teigen et al., 2007). The phrasing of the judgment task directs the decision maker's attention toward evaluating whether the target of judgment meets or fulfills that descriptive state, and the decision maker samples different information according to the perspective or reference defined by the frame. For example, a weather forecast predicting that the chance of rain is "greater than 60%" guides attention toward the occurrence whereas a forecast of "less than 70%" guides attention toward the non-occurrence of rain. In that way, a decision maker's judgment in response

to a frame is analogous with selectively testing a focal hypothesis defined by that frame (Teigen, 2015). Research in political science on emphasis framing similarly asserts that framing focuses attention on a certain perspective or issue, and consequently that focal issue will have greater weight during the judgment process because of its increased accessibility and applicability (Block & Keller, 1995; Chong & Druckman, 2007; Scheufele & Tewksbury, 2007).

From the perspective of the attention account of framing, we might expect the use of the term *safe* in the question to focus the decision maker's attention on sampling evidence to test the hypothesis that the scenario is indeed safe. Yet when uncertainty is high and definitive evidence is lacking, the decision maker might be expected to conclude that the scenario is not safe because of the insufficiency of evidence in support of that hypothesis. The term *dangerous* in the question would similarly focus the decision maker's attention on searching for evidence of danger. When no definitive evidence of danger is found, the decision maker would conclude that the scenario is not dangerous because of the insufficiency of evidence in support of that hypothesis. According to the attention account of framing, one would expect judging how safe a situation is to elicit more cautious, more conservative judgments (i.e., *lower* judged safety ratings) than judging how dangerous a situation is under conditions of uncertainty. Conversely, one would expect judging how dangerous a situation is to elicit less cautious, less conservative judgments (i.e., *lower* danger rating or, conversely, *higher* judged safety ratings) than judging how safe a situation is. Importantly, however, it is unclear whether uncertainty is a necessary condition for the cognitive process described by the attention account to produce a framing effect. One could reasonably assume that there would be no question framing effect when encountering sufficient evidence to establish objective safety under the safe frame, or when encountering sufficient evidence to establish objective danger under the danger frame. Although the question frame likely directs

evidence sampling under all conditions of (un)certainty, this might only result in a framing effect under conditions of objective uncertainty.

Summary and Research Hypotheses

Three influential accounts of framing make opposing predictions about how the question frames we tested might affect the perceived risk of scenarios of backcountry skiing in avalanche terrain. It is important to note, however, that none of these accounts were developed in the context of qualitatively framing the question that elicits a judgment. Nevertheless, all of these accounts have been used to explain different types of question frames, as reviewed above. Our study differs from previous research investigating these accounts of framing in that we presented participants with highly uncertain visual scenarios in addition to verbal question frames.

Although both the valence account and the communication account of framing might predict that judging how safe a situation is would initially elicit higher judged safety, neither account makes strong predictions about how participants subsequently search for information. It is also possible that several or all of the cognitive processes proposed by the different accounts of framing are activated simultaneously or sequentially upon encountering the question frame, in which case we might expect a mixture of effects or no overall effect of framing whatsoever. We test the effect of question framing under conditions of objective uncertainty, safety, and danger in order to ascertain the direction(s) of the effect(s), and thereby infer the cognitive processes activated by a risk judgment framed in terms of safety or danger.

Based on our review of the abovementioned accounts of framing, we predicted in Studies 1 to 4 that the framing of the question that elicited the risk judgment would influence the judged safety of the scenarios, all of which were of uncertain risk. In line with previous work on valence-consistent question framing (e.g., Payne et al., 2013), in Studies 1 and 2 we predicted that a risk judgment phrased as “*How safe is it?*” would elicit higher judged safety than a risk judgment

phrased as “*How dangerous is it?*” When the results of Studies 1 and 2 did not confirm this valence-consistent hypothesis, we updated the direction of the predicted effect in Studies 3 and 4 according to the attention account of framing (see, e.g., Keren, 2011). We predicted that the question “*How safe is it?*” would elicit lower judged safety than the question “*How dangerous is it?*” In Studies 5 and 6, we investigated whether the direction of the question framing effect is consistent when judging scenarios of different objective risk levels. We tested two competing hypotheses: 1) the experimental condition would have the same effect on the judged safety of all scenario categories, versus 2) the experimental condition would only influence the judged safety of scenarios of uncertain risk and there would be negligible effects for objectively safe and dangerous scenarios. Finally, we also predicted for all six studies that the variable judged safety would predict behavior intention. In what follows, we report the methods of data collection and analysis that were common for all six studies, and specify any aspects that were unique to any study. We then report the results of each of the six studies.

Methods of Data Collection and Analysis for Studies 1 to 6

Across six studies ($N = 1599$), we tested how risk perceptions and decisions are influenced by the qualitative frame of the question that elicits the risk judgment (i.e., the question frame). Using a series of hypothetical scenarios involving backcountry skiing in avalanche terrain, participants judged either *how safe* or *how dangerous* each scenario was and indicated whether they would ski the scenario. We confirm that at the time of writing, the six studies reported in this article are all the studies we conducted on the effect of question framing on risk judgments and decisions. We report all measurements assessed and all manipulations implemented in each study. The studies were approved by the Department of Psychology Research Ethics Committee, UiT The Arctic University of Norway. All studies except Study 4

were pre-registered. The pre-registrations, data, R script for data processing and analysis, and the scenarios used in the studies are available on the Open Science Framework (<https://osf.io/sknxf/>).

Participants. Table 1 presents the sample size and information about the sample for each of the six studies. Due to a technical failure, we were unable to collect data on participant age, gender, or experience measures in Study 1. Each of the six studies was conducted during a public seminar on safety and decision-making for backcountry skiers in avalanche terrain, with the seminar audience members as participants. Each seminar was at a different location in Norway during the winter of 2019 to 2020. The audience members at the six seminars were recreational backcountry skiers with varying degrees of experience judging avalanche risk during ski tours in avalanche terrain. Consequently, there was a self-selection for experienced participants in all six studies. Table 2 presents descriptive statistics on participants' experience with the judgment tasks and the activity presented in the scenarios. The seminar in which we conducted Study 1 had a nominal entry fee of NOK 50 (approximately 6 USD) whereas the other five seminars were free to attend. Participation was voluntary and all participants indicated their informed consent to participate. All six studies were conducted in Norwegian.

We did not conduct a priori power analysis to determine target sample size for any study. The audience size at a seminar determined the possible number of participants in the study conducted at that event. We recruited as many participants as possible during each seminar and did not continue data collection for the respective study beyond that seminar, but otherwise had no control over the final sample size of each study. We set a minimum sample size for each study of approximately 60% of the anticipated audience size for that seminar. Participation exceeded 60% of the actual audience size for all six studies and we met the estimated minimum number of participants for Studies 1 to 5. Although more than 60% of the audience participated in Study 6,

we overestimated the expected audience size and did not meet the minimum number of expected participants.

Table 1

Participants in Studies 1 to 6, including sample sizes, division of participants by experimental condition, and data on participants' gender and age. Gender self-identification categories are male (M), female (F), other (O), withheld (W), and data not available (NA). Gender and age data are unavailable for Study 1.

Study	N	Experimental condition		Gender self-identification					M age	SD age	Range age
		Safe	Danger	M	F	O	W	NA			
1	735	351	384	-	-	-	-	735	-	-	-
2	197	102	95	131	53	2	1	10	37	10.95	18-62
3	255	132	122	156	99	0	0	0	38	11.40	18-65
4	173	86	87	90	81	2	0	0	37	11.79	18-73
5	168	66	102	94	74	0	0	0	32	10.17	18-67
6	71	32	39	35	34	2	0	0	29	8.91	19-53

Table 2

Participant experience with the judgment tasks for Studies 1 to 6, including average number of years skiing in avalanche terrain (M_{Years} , response scale from 0 to 40 years), average number of days in avalanche terrain per season (M_{Days} , response scale from 0 to 100 days), and median level of self-reported avalanche safety training ($M_{Training}$, reported on 7-point scale with “1 – None” and “7 – Expert level qualifications” at the scale ends).

Study	N	M_{Years}	M_{Days}	$M_{Training}$
1	735	-	-	-
2	197	8.51	12.02	3
3	255	11.77	14.38	2
4	173	9.54	15.03	2
5	168	7.87	8.36	3
6	71	8.10	28.17	3

Design. All six studies used the same experimental design, measures, and procedures described here. We used a between-subject design with two experimental conditions—the Safe Group or the Danger Group—for the qualitative attribute that framed the risk judgments. All judgment tasks were programmed in Qualtrics. One seminar leader conducted Studies 1, 2 and 6, another seminar leader conducted Studies 3 and 5, and a third seminar leader conducted Study 4. Each seminar began with a presentation of the information resources that are publicly available online from the Norwegian Avalanche Warning Service. After that, the seminar leader announced the study explaining that researchers were investigating information use for avalanche risk judgments. The seminar leader then projected the link to the online study for participants to access via their internet connected mobile devices. Upon accessing the study, participants were randomly assigned by the software to one of the two experimental conditions after indicating their informed consent to participate.

Materials. Participants judged a series of hypothetical scenarios of backcountry skiing in avalanche terrain. Each scenario consisted of a photograph of a person skiing a snow-covered slope (one scenario photo included three people). We hold the rights of use for all photos. In the upper right corner of each photograph were icons indicating the slope angle, the prevailing regional avalanche problem(s), and the forecasted regional avalanche danger level (5-point scale) for that scenario. The icons used are standardized icons defined by the European Avalanche Warning Services (EAWS) and used by the Norwegian Avalanche Warning Service in daily regional avalanche danger forecasts throughout the country. These icons provide valuable objective information for judging the degree of risk.

We developed three categories of scenarios: scenarios of uncertain risk, safe scenarios, and dangerous scenarios, as defined by avalanche experts. An avalanche expert selected photographs from a personal library and assigned icons to those photographs to create scenarios

of differing risk level. The combination of visual evidence in the photograph and the information conveyed by the icons established the objective risk level of each scenario. Uncertain scenarios lacked definitive evidence of safety or danger because the available evidence in the photo and the icons were ambiguous and/or conflicting. For example, although the icons on the steepness of the slope and the prevailing avalanche problems together indicate an increased probability of an avalanche, the icon indicating a danger level of two (on a five-point scale) and the terrain features depicted in the photograph indicate a reduced probability of avalanche. The risk level of that scenario would be objectively uncertain given the conflicting evidence. By contrast, the photographs and icons in the safe and dangerous scenarios conveyed sufficient evidence to ascertain the objective safety or danger of the scenario. For example, although an icon indicates the prevailing regional avalanche problem, no signs indicative of the presence of that problem are evident in the photograph. Additional icons in that scenario indicate a low regional danger forecast and a low slope angle. That scenario is objectively safe because all the evidence align to indicate that an avalanche is extremely unlikely. The objective uncertainty of the uncertain scenarios, the objective safety of the safe scenarios, and objective danger of the dangerous scenarios were established by the avalanche expert who designed the scenarios, and independently confirmed by a second avalanche expert. All scenarios used in the six studies are available on the Open Science Framework at <https://osf.io/sknxf/>.

Participants in Studies 1 to 4 judged six uncertain scenarios. We used the same six uncertain scenarios for all four studies, changing their order of presentation between studies to account for any possible order effect. Participants in Studies 5 and 6 judged ten scenarios: four scenarios of uncertain risk, three safe scenarios, and three dangerous scenarios. We used the same set of ten scenarios for both studies. The four uncertain scenarios used in Studies 5 and 6 were selected from among the six uncertain scenarios previously used in Studies 1 to 4. The three safe

scenarios and the three dangerous scenarios used in Studies 5 and 6 were new. We anticipated the possibility of an effect from the order in which the categories of scenarios were judged. We therefore reversed the order of presentation between Studies 5 and 6. In Study 5, we first presented the three dangerous scenarios followed by the four uncertain scenarios, and lastly the three safe scenarios. In Study 6, we first presented the three safe scenarios, then the four uncertain scenarios, and finally the three dangerous scenarios. Although we reversed the order of the scenario categories in Study 6, the order of the scenarios within each category was the same in both studies.

Measures. The scenarios were sequentially projected onto the auditorium screen for all participants in the audience to see. All questions were displayed exclusively in Qualtrics on participants' personal mobile devices. Participants in the Safe Group judged the scenarios by answering the question "*How safe is it?*" responding on a 7-point scale labeled "*Not at all safe*" and "*Completely safe*" at the extreme points. Participants in the Danger Group judged the same scenarios by answering the question "*How dangerous is it?*" responding on a 7-point scale labeled "*Not at all dangerous*" and "*Completely dangerous*" at the extreme points. Upon completing each risk judgment, participants in both experimental groups were asked the question "*Would you ski this slope?*" with the three response options "*No*", "*I cannot say*" or "*Yes*". Participants had approximately one minute per scenario to answer the risk judgment and the behavior intention questions before the next scenario was projected. Participants were instructed not to discuss with their neighbors during the study and the seminar leaders confirmed that all auditoriums were silent during data collection. Participants were not required to answer the questions to proceed to the next scenario. Upon completing the scenarios, participants answered questions about their age, gender, and nationality. Finally, participants reported their skiing ability, avalanche training, years of backcountry skiing experience, average number of

backcountry skiing days per season, and past exposure to avalanche incidents. However, due to a technical failure, these covariates were not measured at all locations and are therefore not considered in our analysis.

Data preparation and analysis: We used R (R Core Team, 2017) for all data preparation and analyses. We reverse coded the risk judgment scores of participants in the Danger Group to make them comparable to the risk judgments of participants in the Safe Group. We henceforth refer to the judged risk as *judged safety* for both experimental conditions. There were missing values of judged safety (Study 1 = 2.3%; Study 2 = 5.1%; Study 3 = 1.0%; Study 4 = .5%; Study 5 = .1%; Study 6 = .6%) and behavior intention (Study 1 = 2.4%; Study 2 = 4.6%; Study 3 = 1.2%; Study 4 = .4%; Study 5 = .1%; Study 6 = 0%) within the data. We deemed those values to be missing at random. Mixed model analyses can handle missing values without requiring the exclusion of participants for whom only partial data was collected (Baayen et al., 2008). We therefore did not impute any data for missing values. For Studies 5 and 6, we subset the data by scenario category. We treated judged safety and behavior intention as ordinal variables. To examine whether the experimental condition influenced the odds of each value of judged safety, we used the *ordinal* package (Christensen, 2019) to implement cumulative link mixed models via Laplace approximations for the hypothesized model with judged safety as the outcome variable and the experimental condition as the predictor variable. We included intercepts for participants and scenarios as random effects to account for by-subject and by-scenario variability. We calculated Chi-square values (χ^2) with likelihood-ratio tests comparing the model that included the predictor variable(s) under investigation as the fixed effect (and participants and scenarios as random effects) against an equivalent model that excluded that predictor variable(s). To examine predictors of behavior, we estimated ordinal mixed models via Laplace approximations to analyze whether the predictor variables experimental condition, judged safety or their interaction

predicted the odds of the outcome variable self-reported behavior intention. We defined the response order of behavior intention as “No” < “I cannot say” < “Yes”. We treated the predictor judged safety as an interval variable for all analyses involving behavior intention as the outcome variable. We included intercepts for participants and scenarios as random effects, thereby accounting for by-subject and by-scenario variability. We calculated Chi-square values (χ^2) with likelihood-ratio tests using the method described above.

Results

Studies 1 to 4: Single Reference Judgments of Uncertain Scenarios

Table 3 presents the proportions of judged safety values per experimental condition for Studies 1 to 4, with mode values clearly marked. The experimental condition influenced judged safety in all studies: Study 1, $\chi^2(1) = 30.49, p < .001$; Study 2, $\chi^2(1) = 12.25, p < .001$; Study 3, $\chi^2(1) = 19.65, p < .001$; and Study 4, $\chi^2(1) = 8.14, p = .004$. The log-odds coefficients and odds ratios for the main effect experimental condition for each study are presented in Table 4.

Participants in the Danger Group who judged “*How dangerous is it?*” were at least 1.6 times more likely to judge a scenario to be safer than participants in the Safe Group who judged “*How safe is it?*”. The probabilities of each value of judged safety per experimental condition are presented in Figure 1. In all four studies, judged safety was higher when judged in terms of how dangerous the scenario was than when judged in terms of how safe the scenario was.

Table 3 presents the proportions of behavior intention values per experimental condition for Studies 1 to 4, with mode response clearly marked. Judged safety predicted behavior intention in all four studies: Study 1, $\chi^2(1) = 1995.60, p < .001$, Study 2, $\chi^2(1) = 451.93, p < .001$, Study 3, $\chi^2(1) = 609.66, p < .001$, and Study 4, $\chi^2(1) = 388.44, p < .001$. The experimental condition alone, as a main effect, marginally predicted behavior in Study 2, $b = -.37, SE = .20, \chi^2(1) = 3.56, p = .059$, although that effect is mediated by the main effect judged safety (see Table 5). Otherwise,

the experimental condition alone did not predict behavior in Studies 1, 3 or 4. The addition of the main effect experimental condition to the model with the main effect judged safety predicted behavior intention in Study 1, $\chi^2(1) = 17.76, p < .001$, and Study 3, $\chi^2(1) = 11.51, p < .001$, and marginally predicted behavior in Study 4, $\chi^2(1) = 2.69, p = .101$. The log-odds coefficients and odds ratios for the influence of the main effects judged safety and experimental condition on behavior intentions are presented in Table 5. Figure 2 illustrates the probability of each behavior per judged safety value per experimental condition. An interaction between the experimental condition and judged safety did not predict behavior intention in any of the four studies: Study 1, $\chi^2(1) = 1.56, p = .211$, Study 2, $\chi^2(1) = 1.05, p = .305$, Study 3, $\chi^2(1) = .02, p = .896$, or Study 4, $\chi^2(1) = .00, p = .949$. Overall we found that as the value of judged safety increased, the probability that participants in both experimental groups would ski the slope in the scenario increased. If participants in both experimental conditions judged safety to be equal, the probability that participants in the Safe Group would ski a slope was higher than that of participants in the Danger Group. However, based on the magnitude of the log-odds coefficients and the odds ratios, judged safety had the greatest predictive power of behavior intention. Consequently, participants in the Safe Group were qualitatively less inclined to indicate that they would ski a slope because they were more likely to judge safety as lower.

To further investigate the robustness and scope of these measured effects, we conducted two additional studies using a broader set of scenarios with different levels of objective risk. Participants in Studies 1 to 4 judged scenarios that were all of uncertain risk. Is it possible that the high degree of uncertainty in some way influenced or accounted for the observed effect? Is uncertainty a prerequisite for the effect or does the question framing effect extend to situations that are objectively safe or dangerous? These are important questions because in a real world context, people encounter a range of situations of different objective risk with varying degrees of

uncertainty. Understanding the contexts to which the observed question framing effect extends will inform strategies for its potential application. We therefore conducted Studies 5 and 6 using scenarios in three categories of objective risk—uncertain scenarios, safe scenarios, and dangerous scenarios—to examine if the effect observed in Studies 1 to 4 is present under varying degrees of objective risk and uncertainty.

Table 3

Percentage of judged safety values (values 1 to 7) and percentage of behavior (No = No, I would not ski the slope, UD = Undecided, I cannot say, and Yes = Yes, I would ski the slope) per experimental condition for Studies 1-4. The mode judged safety value and the mode behavior per experimental condition is marked by bold font.

Frame	Judged safety score							Behavior		
	1	2	3	4	5	6	7	No	UD	Yes
Study 1										
Safe	17.7	21.2	22.0	17.4	14.2	5.7	1.8	49.7	7.9	42.4
Danger	12.7	15.5	23.1	22.5	17.9	7.3	1.0	49.9	5.5	44.6
Study 2										
Safe	24.0	27.0	20.6	13.5	9.9	4.1	.9	56.6	8.9	34.5
Danger	18.9	17.5	22.0	21.0	14.1	6.1	.4	52.2	4.2	43.6
Study 3										
Safe	22.9	19.8	21.6	20.1	12.0	2.4	1.2	47.1	6.1	46.8
Danger	11.8	17.0	24.0	25.3	17.5	3.7	.7	45.9	7.7	46.4
Study 4										
Safe	25.2	26.6	24.1	16.1	5.6	2.0	.4	61.8	6.6	31.6
Danger	18.5	23.0	23.4	19.7	12.7	2.5	.2	60.8	3.5	35.7

Table 4

Coefficients of the model (judged safety ~ experimental condition) predicting whether the experimental condition influences judged safety for Studies 1-4

	$b_{\text{Danger frame}} (SE)$	95% CI for Odds Ratios (OR)			p-value
		Lower	OR	Upper	
Study 1	.47 (.08)	1.36	1.60	1.89	< .001
Study 2	.63 (.18)	1.33	1.89	2.68	< .001
Study 3	.72 (.16)	1.50	2.04	2.79	< .001
Study 4	.60 (.21)	1.21	1.81	2.72	.004

Figure 1

Probabilities of judged safety values by experimental condition, with 95% confidence intervals, for Studies 1-4.

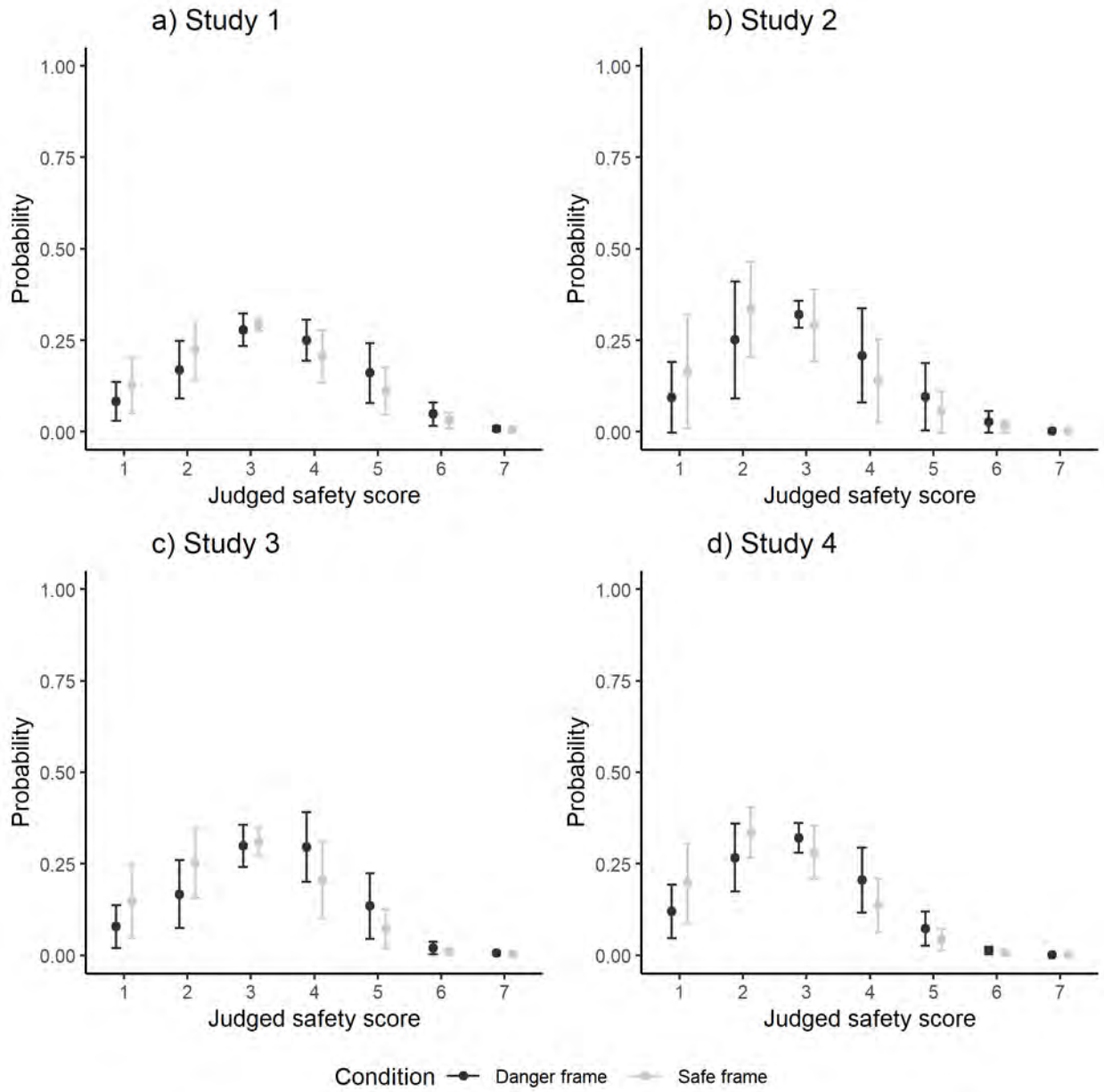


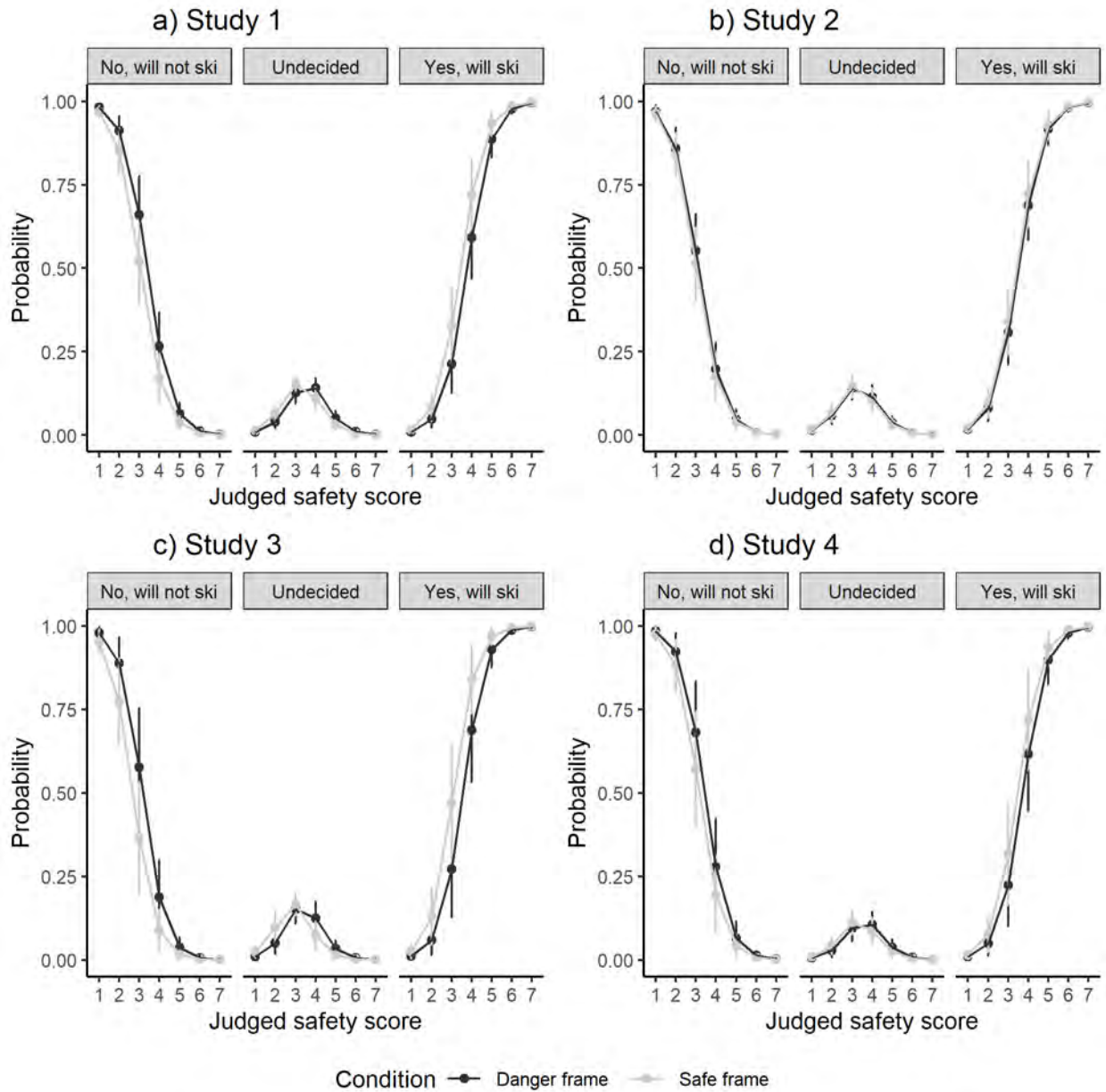
Table 5

Coefficients of the model (behavior ~ judged safety + experimental condition) predicting whether the terms judged safety and experimental condition influences behavior intention in Studies 1-4

	<i>b</i> (<i>SE</i>)	95% <i>CI</i> for Odds Ratios (OR)			<i>p</i> -value
		Lower	OR	Upper	
Study 1					
Judged safety	1.67 (.06)	4.76	5.34	5.98	< .001
Safe frame	.57 (.14)	1.36	1.78	2.32	< .001
Study 2					
Judged safety	1.60 (.11)	3.98	4.98	6.23	< .001
Safe frame	.15 (.26)	.69	1.17	1.96	.562
Study 3					
Judged safety	1.77 (.11)	4.78	5.90	7.29	< .001
Safe frame	.86 (.25)	1.43	2.36	3.88	< .001
Study 4					
Judged safety	1.71 (.13)	4.30	5.54	7.13	< .001
Safe frame	.47 (.29)	.91	1.60	2.80	.101

Figure 2

Probabilities, with 95% confidence intervals, of skiing the scenario slope by judged safety values and experimental condition for Studies 1-4.



Studies 5 and 6: Single Reference Judgments of Uncertain, Safe and Dangerous Scenarios

Table 6 presents the proportions of judged safety values per experimental condition for each category of scenarios in Studies 5 and 6, with the mode values clearly marked. In Study 5, the experimental condition influenced judged safety—presented according to the order in which participants judged the categories of scenarios—for dangerous scenarios, $\chi^2(1) = 52.59, p < .001$, and scenarios of uncertain risk, $\chi^2(1) = 10.28, p = .001$, but did not influence the judged safety for safe scenarios, $\chi^2(1) = .55, p = .457$, which participants judged last. In Study 6, the experimental condition influenced judged safety—presented according to the order in which participants judged the categories of scenarios—of safe scenarios, $\chi^2(1) = 12.45, p < .001$, did not influence the judged safety of scenarios of uncertain safety, $\chi^2(1) = 2.29, p = .130$, and influenced the judged safety of dangerous scenarios, $\chi^2(1) = 85.37, p < .001$. The log-odds coefficients and odds ratios for the main effect experimental condition per scenario category are presented in Table 7. The probabilities of each value of judged safety per scenario category by experimental condition are presented in Figure 3. Apart from the safe scenarios that were judged last in Study 5 and the uncertain scenarios that were judged second in Study 6 for which there was no effect, participants in the Danger Group were more likely to judge all categories of scenarios to be safer than participants in the Safe Group. Study 5 and Study 6 replicated the result that framing the risk judgment in terms of safety was more likely to result in lower judged safety whereas framing the risk judgment in terms of danger was more likely to result in higher judged safety.

Table 6 presents the proportions of behavior intention values per experimental condition for Studies 5 and 6, with the mode response clearly marked. The main effect judged safety predicted behavior intention for safe scenarios in Study 5, $\chi^2(1) = 112.21, p < .001$, and Study 6, $\chi^2(1) = 113.67, p < .001$; for uncertain scenarios in Study 5, $\chi^2(1) = 322.23, p < .001$, and Study 6,

$\chi^2(1) = 133.74, p < .001$; and for dangerous scenarios in Study 5, $\chi^2(1) = 28.32, p < .001$, and Study 6, $\chi^2(1) = 3.14, p < .076$. The experimental condition alone, as a main effect, predicted behavior for safe scenarios in Study 6, $\chi^2(1) = 8.47, p < .003$; an effect that is mediated by the main effect judged safety (see Table 8). Otherwise, the experimental condition alone did not predict behavior intention in either Study 5 or Study 6. The addition of the main effect experimental condition to the model with the main effect judged safety predicted behavior intention for uncertain scenarios in Study 5, $\chi^2(2) = 6.41, p = .011$, and an interaction between judged safety and the experimental condition predicted behavior for the safe scenarios in Study 5, $\chi^2(1) = 6.78, p = .009$. However, the experimental condition had no influence on behavior for the safe scenarios or the uncertain scenarios in Study 6 beyond what was predicted by judged safety. The log-odds coefficients and odds ratios for the influence of the main effect judged safety together with the main effect experimental condition (and their interaction, if relevant) on behavior intentions are presented in Table 8. As the value of judged safety increased, the probability that participants in both experimental groups would ski the slope increased for safe scenarios and scenarios of uncertain risk. Studies 5 and 6 replicated the result that judged safety had the greatest predictive power of behavior intention. Participants in the Safe Group were therefore qualitatively less inclined to indicate that they would ski a slope because they were more likely to judge safety as lower. As for dangerous scenarios, there were too few measures of judged safety values greater than 4 in Study 5 and greater than 3 in Study 6 to reliably test for an interaction effect between judged safety and experimental condition. This is indicated by the range of the 95% CI in Figure 4. Participants in both experimental groups in Studies 5 and 6 were effectively unanimous that it was 100% likely that they would not ski the slopes in the dangerous scenarios.

Table 6

Percentage of judged safety values (values 1 to 7) and percentage of behavior (No = No, I would not ski the slope, UD = Undecided, I cannot say, and Yes = Yes, I would ski the slope) per experimental condition (column Group) and per scenario category (column Scenario, S = safe, UR = uncertain risk, and AD = dangerous) for Studies 5 and 6. The mode judged safety value and the mode behavior per experimental condition and per scenario category is marked by bold font.

Frame	Scenario	Judged safety score							Behavior		
		1	2	3	4	5	6	7	No	UD	Yes
Study 5											
Safe	Safe	1.0	3.1	6.6	11.7	22.3	34.5	20.8	8.6	2.0	89.4
Danger	Safe	.0	1.0	6.8	10.8	23.9	37.9	19.6	5.6	2.9	91.5
Safe	Uncertain	11.7	27.6	29.6	19.7	9.8	.8	.8	59.1	9.1	31.8
Danger	Uncertain	8.6	15.9	26.5	30.4	14.7	3.4	.5	57.1	7.6	35.3
Safe	Dangerous	66.2	25.8	6.0	2.0	.0	.0	.0	96.0	2.5	1.5
Danger	Dangerous	37.2	24.5	15.7	13.4	6.9	1.6	.7	95.1	.3	4.6
Study 6											
Safe	Safe	3.2	7.4	14.9	18.1	28.7	14.9	12.8	16.7	13.5	69.8
Danger	Safe	.8	2.6	6.8	9.4	29.1	29.9	21.4	10.2	2.6	87.2
Safe	Uncertain	26.0	32.3	23.6	9.4	5.5	2.4	.8	68.7	13.3	18.0
Danger	Uncertain	21.9	22.0	31.6	14.2	10.3	.0	.0	69.2	10.3	20.5
Safe	Dangerous	92.7	6.3	1.0	.0	.0	.0	.0	96.9	2.1	1.0
Danger	Dangerous	55.6	13.7	20.5	6.0	4.3	.0	.0	97.4	2.6	.0

Table 7

Coefficients of the model (judged safety ~ experimental condition) predicting whether the experimental condition influences judged safety per scenario category for Studies 5 and 6.

	<i>b</i> _{Danger frame} (SE)	95% CI for Odds Ratios (OR)			<i>p</i> -value
		Lower	OR	Upper	
Study 5					
Safe scenarios	.20 (.27)	.72	1.22	2.08	.457
Uncertain scenarios	.88 (.27)	1.42	2.42	4.15	.001
Dangerous scenarios	1.97 (.28)	4.14	7.17	12.42	< .001
Study 6					
Safe scenarios	1.62 (.46)	2.07	5.08	12.45	< .001
Uncertain scenarios	.43 (.28)	.88	1.53	2.66	.130
Dangerous scenarios	3.35 (.64)	8.06	28.42	100.18	< .001

Figure 3

Probabilities of judged safety values per experimental condition and per scenario category, with 95% confidence intervals, for Studies 5 and 6.

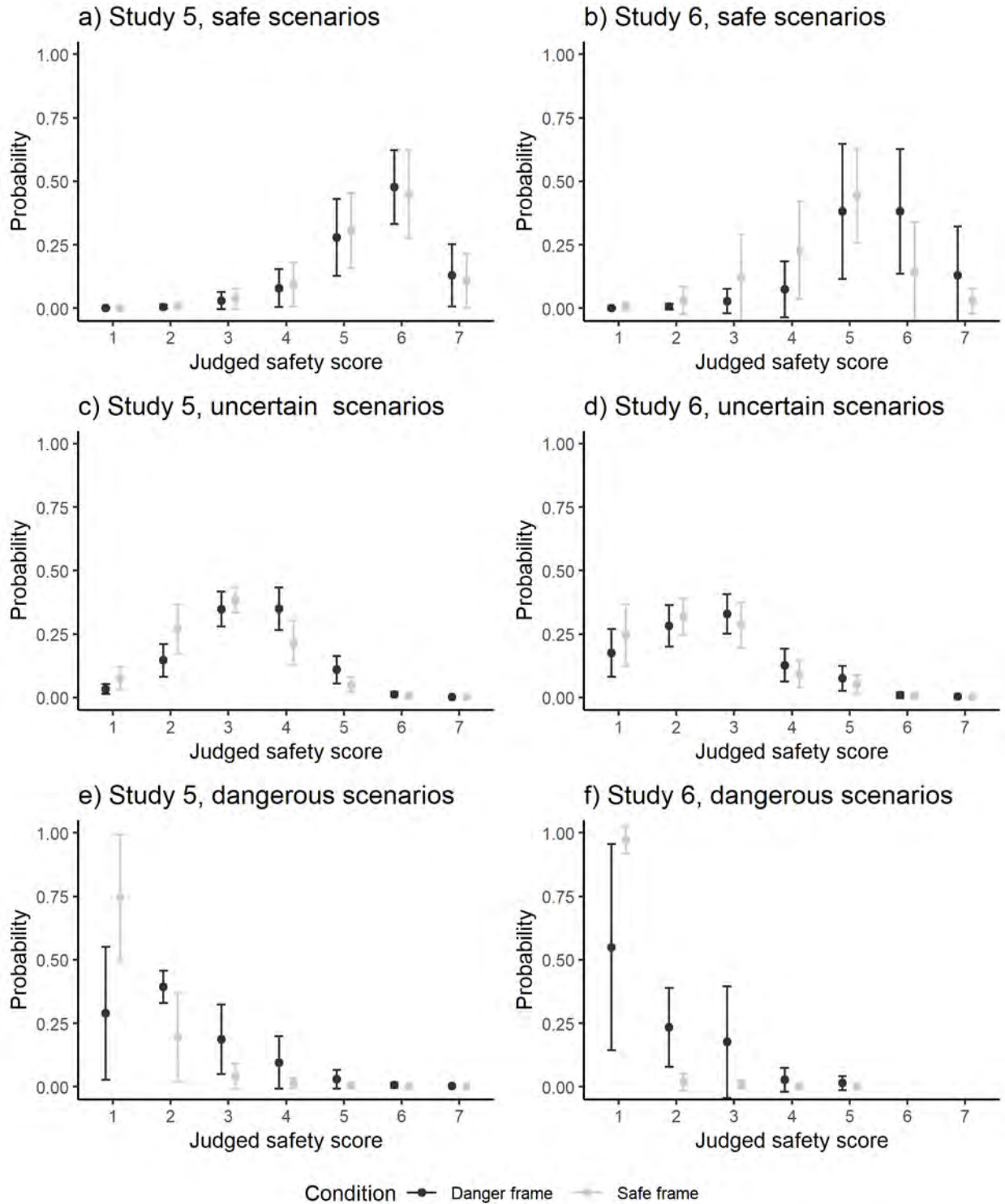


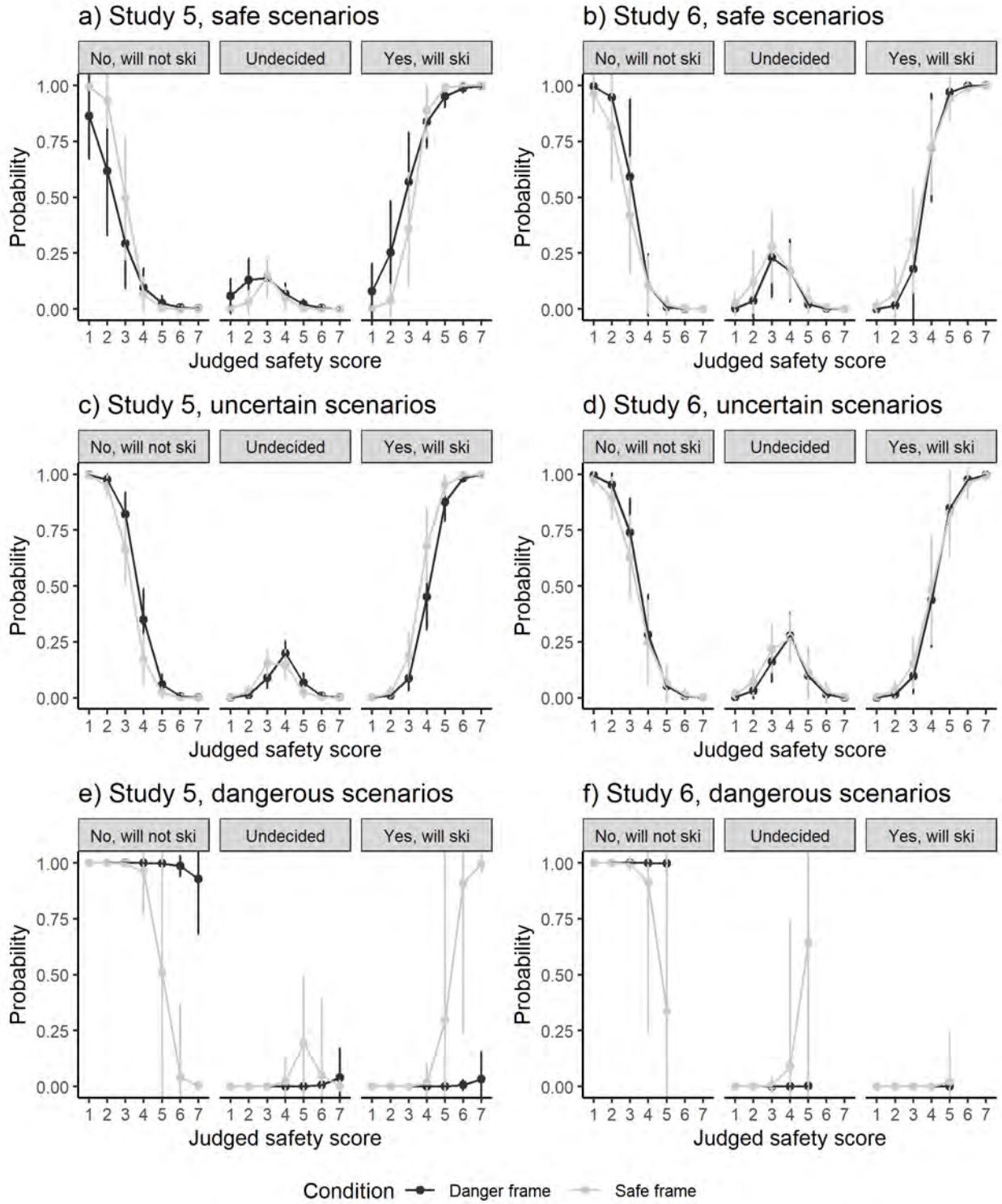
Table 8

Coefficients of the model predicting whether the terms judged safety and experimental condition influences behavior intention per scenario category in Studies 5 and 6

	<i>b</i> (<i>SE</i>)	Odds Ratios (OR) 95% CI			<i>p</i> -value
		Lower	OR	Upper	
Study 5, safe scenarios					
Judged safety	1.36 (.28)	2.25	3.90	6.75	< .001
Safe frame	-4.71 (2.23)	.00	.00	.71	.034
Judged safety * safe frame	1.28 (.59)	1.14	3.60	11.39	.029
Study 5, uncertain scenarios					
Judged safety	2.18 (.19)	6.11	8.88	12.91	< .001
Safe frame	.89 (.35)	1.22	2.44	4.88	.012
Study 6, safe scenarios					
Judged safety	2.02 (.46)	3.09	7.56	18.46	< .001
Safe frame	.11 (.55)	.37	1.11	3.33	.849
Study 6, uncertain scenarios					
Judged safety	1.79 (.25)	3.68	6.00	9.78	< .001
Safe frame	.50 (.47)	.65	1.65	4.19	.288

Figure 4

Probabilities, with 95% confidence intervals, of skiing the scenario slope by judged safety values per experimental condition per scenario category for Studies 5 and 6.



General Discussion

Results from six studies demonstrate that risk perception is influenced by the frame of the question that elicits the risk judgment. Framing a risk judgment in terms of safety (“*How safe is it?*”) was more likely to result in lower judged safety than framing that risk judgment in terms of danger (“*How dangerous is it?*”). The results of Studies 5 and 6 indicate that uncertainty is not a prerequisite for this framing effect. The question frame had a consistent direction of effect when judging safe scenarios, uncertain scenarios, and dangerous scenarios, suggesting that, in principle, the effect from framing risk judgments in terms of safety or danger applies in all situations of objective risk.

Question Frames Guide Attention during Information Sampling

A question frame elicits a judgment that is relative to the reference defined by the frame. This process can be thought of as analogous to testing the hypothesis defined by the frame. The question “*How safe is it?*” defines *safe* as the provisional reference point for the risk judgment, whereas the question “*How dangerous is it?*” defines *dangerous* as the provisional reference point for the risk judgment. This has the effect of focusing the decision maker’s attention on selectively sampling evidence to evaluate whether the target of judgment meets or fulfills the descriptive state defined by the question frame rather than judging the degree of risk according to the two complementary poles *completely safe* and *completely dangerous*. Participants presented the safe frame judged whether the available evidence was sufficient to establish whether a scenario was indeed safe. Participants presented the danger frame judged the available evidence with a focus on ascertaining whether the same scenario was indeed dangerous. To ask how safe a scenario is or to ask how dangerous it is are therefore not informationally equivalent frames, despite being complementary dimensions of the bipolar attribute *risk*. Each question focuses the decision maker’s attention on selectively sampling different evidence in relation to different

reference points (Chong & Druckman, 2007; Druckman, 2001; Keren, 2011; Teigen, 2015), effectively making each question a different judgment task. This is particularly relevant in a decision environment such as avalanche terrain where information cues rarely have logically equivalent opposites. There is an asymmetry of relevant evidence between the frames. Although the presence of one sign indicates increased danger and the greater probability of an avalanche, that sign may have no logically equivalent opposite. Moreover, the absence of that sign is not necessarily an indication of increased safety.

Participants in our studies sampled different evidence in relation to the reference point defined by the question frame and reported their judgment on a scale similarly defined by that reference point. As illustrated in Figure 5, participants searched for evidence of safety if *safe* framed the question eliciting the risk judgment, or searched for evidence of danger if *danger* framed the question. Yet under conditions of high uncertainty, there was insufficient evidence to definitively establish or reject the descriptive state that either reference point emphasized. The evidence in favor of either reference point was ambiguous and therefore participants judging safety concluded that a scenario was not definitively safe, whereas participants judging danger similarly concluded that the same scenario was not entirely dangerous. Under both frames, participants adjusted their reported judgment according to the perceived (in)sufficiency of evidence for their respective reference point defined by the question frame. Those adjustments were made in relation to the limits, also defined by the question frame, of their respective reporting scales. However, the available evidence and consequently the adjustment on the response scale differed between the framing conditions. As a result, participants who were presented the safe frame judged the scenarios to be relatively more dangerous (alternatively, relatively less safe), while participants who were presented the danger frame judged the same scenarios to be relatively safer (alternatively, relatively less dangerous).

Interestingly, we observed this effect when participants judged dangerous and safe scenarios. Despite the availability of what avalanche experts consider to be definitive evidence of the objective safety and danger of the scenarios, participants who faced the safe frame did not accept the reference point *safe* for safe scenarios, and consequently judged them to be relatively less safe than participants who faced the danger frame did. Similarly, when judging dangerous scenarios, those who faced the danger frame did not accept the reference *danger* defined by that frame, and consequently judged dangerous scenarios to be relatively less dangerous (i.e., more safe) than participants under the safe frame. Objective uncertainty was not a requirement for the question frame to evoke selective evidence sampling relative to the reference point defined by the frame. Although a framing effect was not measured for judgments of safe scenarios in Study 5 and uncertain scenarios in Study 6, we suspect this to be the result of the order in which participants judged the scenarios. When judging scenarios of different objective risk levels, participants might have judged a given scenario in relation to the sufficiency of evidence and the judged safety/danger of the previous scenario(s). We also suspect that an order effect was the cause of the different magnitude of measured effects between scenarios categories in Studies 5 and 6. Examining the role of presentation order more directly may be an interesting direction for future work, but a challenge would be to ensure that such an investigation is ecologically valid. It is unlikely that a person would judge vastly different conditions in close temporal proximity. Thus the order effects we observed here may have been, to some extent, an artifact of overly stark contrasts between objective risk levels.

The Possibility of Other Cognitive Processes during Question Frames

The direction of the question framing effect we observed across six studies runs counter to what might be expected based on alternative accounts of framing that assume a valence or communication driven mechanism. In particular, both the valence account and the

communication account of framing would be consistent with judged safety being higher when judging “How safe is it?” Earlier research found on the direction of the question framing effect and the underlying cognitive processes found conflicting results. Payne and colleagues (2013) found credible evidence of a question framing effect consistent with the valence account of framing. Although Comerford and Robinson (2017) replicated the results of Payne and colleagues when testing the same judgment task, when they replaced the reporting format from a probabilistic estimate to a point estimate, their results indicated a framing effect in the opposite direction.

This apparent mismatch between the predictions of other framing accounts and our findings may be linked to the specific framing paradigm we used. In addition to specifying a verbal question frame (how safe vs. dangerous is it?), the judgment task we used involved sampling information beyond what was described by the question frame. This process of information sampling is not a common element in most judgment tasks used in other research on framing, and the cognitive processes underlying framing effects likely depend on the method by which the frame is achieved. Kreiner and Gamliel (2018), for instance, found evidence that attention mechanisms contribute to attribute framing but recognized that their experimental design prevented them from ruling out the potential contribution of valence mechanisms to the overall framing effect. Similarly, in our paradigm, attentional mechanisms may have played a dominant role because we included an information-sampling component and because the frame was achieved by the phrasing of a question (rather than a statement). Yet we cannot rule out that valence-driven and communicative mechanisms also played a role in the results of our study. Participants’ initial prior when prompted with the question *How safe is it?* may well have leaned toward the valence of that frame, but was then revised in the process of gathering insufficient evidence to support this initial hypothesis. Thus, framing may be an aggregation of different

forces resulting from distinct cognitive processes that are evoked by the judgment task and the manner in which the frame is achieved. An interesting avenue for future research is to use computational cognitive modeling to disentangle the cognitive processes that drive question framing.

Figure 5

A conceptualization of the decision making processes under each experimental framing condition. The person on the left represents the Safe Group judging risk in response to the question “How safe is it?” The person on the right represents the Danger Group judging risk in response to the question “How dangerous is it?” The thought bubbles illustrate the assumed cognitive process up to the behavior decisions expressed in the speech bubbles. The icons in the top left and the “35°” are examples of the information provided in the scenarios. They represent the forecasted regional avalanche danger rating (3), the avalanche problem, and the slope angle.



The Indirect Influence of Question Framing on Behavior Decisions

Beyond the effect of question framing on judged safety, the results from all six studies indicate that judged safety influenced participants' hypothetical behavior intention. The probability that participants would ski the slope monotonically increased with an increase in judged safety. The only exception to this clear result concerned the judgments of dangerous scenarios, for which participants were effectively unanimous that irrespective of judged safety they would not ski the slope (see Figure 4). However, it is very rare for dangerous slopes to be so clearly marked as dangerous, as they were in our studies, by evidence of an active avalanche on that particular slope. Typical of a wicked learning environment (Hogarth et al., 2015), a dangerous slope commonly resembles an uncertain slope until someone travels on it triggering an avalanche, thus providing clear but rare evidence of the objective risk level, albeit a little too late.

Indecision was a response option for the measure of behavior intention, and a small proportion of responses (ranging from .3 to 13.5% across all studies and scenario categories) indicated that participants were undecided about their intended action. The likelihood of such indecision was highest when scenarios were perceived to be neither completely safe nor completely dangerous, with judged safety values in the middle range of the response scale. This establishes that the judged safety response scale captured the equivalent poles of the bipolar attribute of judgment, despite only one of those poles framing the judgment task. However, it is important to point out that indecision is not a true response option in a real-world situation; either skiing the slope or not skiing the slope are only ever observed.

Behavior is what exposes people to risk. That judged safety influenced behavior intention is particularly important for our examination of question framing and the possibility of harnessing that framing effect to promote safer risk judgments and decisions. Although there was no overall effect of framing on hypothetical behavioral intent, it is important to emphasize the

process by which question framing influenced behavior. Question framing was found to influence judged safety, and judged safety was in turn found to be a powerful determinant of behavior decisions. Since behavior is the immediate cause of risk exposure, any factor that can directly or indirectly influence behavior can potentially be utilized to reduce the frequency of accidents and fatalities. Phrasing the risk judgment in terms of how safe the slope is resulted in lower values of judged safety, which in turn resulted in a lower likelihood of deciding to ski the slope. This suggests that judging how safe a risk is will result in the safest behavior with respect to the potential risk. The safe frame was found to indirectly result in more cautious behavior via the direct effect of framing on judged safety. We illustrate the indirect influence of question framing on behavior intention via the effect on judged safety in Figure 5. This illustration is intended to make clear both the presumed cognitive processes and the potential applied relevance of question framing to the widest possible audience. By selectively phrasing the question that elicits a risk judgment, a decision maker's attention can be directed in a way that strategically influences the perception of risk with the effect of making one behavior outcome more likely.

Interestingly, at any given level of judged safety—if participants in the two experimental groups judged safety to be the same—those prompted with the safe frame indicated that they were more likely to ski the slope than were participants prompted with the danger frame. To understand this apparently contradictory effect, consider the conditions under which judged safety will be equal between the two framing conditions. Due to the question framing effect, the judged safety of a given scenario was more likely lower under the safe frame and higher under the danger frame. That framing effect must be offset or overcome in order for judged safety between the two framing conditions to be equal. We can therefore assume that when judged safety under the two frames was equal, the perceived evidence basis for the judgments were not equivalent. The intention to ski may have been higher under the safe frame because that decision

maker perceived more evidence of safety (more in terms of validity, relevance, weight, or even volume of evidence), and/or the intention to ski may be lower under the danger frame because that decision maker perceived similarly more evidence of danger. The behavior decisions under each frame are based on an asymmetry of evidence, an asymmetry that was necessary to offset the framing effect in order for judged safety to be equal. Although we appear to find more risk acceptance under the safe frame when judged safety between the experimental conditions is equal, the behavior decisions under the safe frame are potentially made on a more valid, relevant sample of evidence. Importantly, however, this finding must be placed in the context that judged safety was the strongest predictor of behavior intention. Participants who judged how safe a scenario is were more likely to judge safety as lower, and the likelihood of skiing a slope decreased as judged safety decreased. The safe frame was found to indirectly result in more cautious behavior via the direct effect of framing on judged safety.

Implications for Applied Risk Judgments and Risk Communication

Backcountry skiing in avalanche terrain exemplifies a crucial challenge in applied risk communication and risk perception: people desire to engage in an activity despite knowing the inherent risk of serious injury or death. Avalanche accidents are overwhelmingly the result of human error. In 90% of fatal avalanche accidents, the victim or someone in the victim's party triggered the avalanche (McClung & Schaerer, 2006), implying that people's risk perception and decisions are critical factors in avalanche fatalities. Information on the conditions in avalanche terrain such as the complex conditions of the snowpack, its metamorphosis over time, and the effects of terrain and weather, together with the knowledge of how to use this information are essential for judging avalanche risk. In an attempt to reduce the number of accidents and fatalities, stakeholders such as national avalanche warning services and education providers have done much work to provide detailed avalanche forecasts and improve public knowledge of the

dangers and best practices for safety in avalanche terrain (for a review, see e.g., Engeset et al, 2018). Yet despite these efforts, avalanches continue to claim the lives of a troubling number of participants in this increasingly popular and unregulated activity. The dissemination of information—which as a stand-alone activity is a failed strategy for changing how people perceive risk and behave (Kelly & Barker, 2016; Simis et al, 2016)—has been insufficient for ensuring avalanche safety among backcountry skiers. Might question framing serve as a complementary strategy to promote more cautious risk perception and behavior?

Decision makers, avalanche warning services, and education providers have substantial control over the formulation of questions about the risks assessed during a backcountry ski tour. Our findings illustrate how the language used to formulate risk judgments and its influence on the cognitive processes has the potential for a real and tangible impact on how people perceive risk and, ultimately, behave in the face of risk. Selectively framing risk judgments might serve as one effective component of a multifaceted strategy to promote more cautious and conservative decisions in avalanche terrain and other domains involving risks. These findings have potential real-world application in teaching methods, tools, and strategies for reducing accidents and fatalities. At the public and institutional level such as a national or regional avalanche forecasting service, the frame used when presenting information about conditions in avalanche terrain might influence how users (i.e. the general public) both perceive the current risk and, more critically, how they decide to act. At the individual or group level, communication between members of a group travelling in avalanche terrain, while typically presented with little thought toward framing, could be positively impacted by increased awareness of the framing effect. Specifically, if a group member is presenting route options or tour alternatives, the way in which information and questions are framed could influence other group members' perceptions of the current risk and the decisions that are made or communicated by members of the group.

Despite the apparent promise, there are several important considerations and potential limitations for the application of question framing to increase skier safety in avalanche terrain, or to promote certain judgments and decisions within any other discipline or context. It is currently an open question whether people can prompt themselves to frame questions about risky situations in a way that promotes safer judgments, highlighting an interesting avenue for future research. It is unlikely that how a decision maker internally represents the problem or judgment is entirely determined by externally presented information and/or the formulation of the judgment task (Tversky & Kahneman, 1981). Decision makers clearly use their own experience and knowledge when modelling the world in order to judge the probabilities of potential outcomes (e.g., Wulff et al., 2019), and they may automatically do so with a familiar, default reference when not prompted with a question frame. Another important consideration is whether *actual behavior* in the mountains, when judging a slope to really ski while facing the real risk of avalanche, would be affected differently than hypothetical behavioral intent measured in an auditorium using fictional scenarios. Behavior often deviates from intention (Sheeran & Webb, 2016). Moreover, contextual cues only encountered in the natural decision environment can reduce an anticipated framing effect (Bless et al., 1998). A third consideration is that we may fail to see the same framing effect outside of the experimental setting. Unlike a natural setting, participants in our study had limited time to judge the risk and decide their behavior intention for each scenario. Although there is conflicting evidence as to whether more thought reduces framing effects (for example, see LeBoeuf & Shafir, 2003; Martiny-Huenger et al, 2020), we may fail to see the same effect in a natural environment where decision makers have more time for reflection and where the potential consequence of error is considerably greater. A fourth consideration is the necessity to establish whether people's natural decision making process is to first judge risk in terms of safety or danger before then deciding behavior. The risk judgment itself may be a contrivance of the

experimental design. Outside of an experimental setting, the behavior decision may encompass the risk judgment. Finally, any application of these findings should be tested in an applied setting before prescribing them for use in practice.

Research on framing effects informs policies and practices in other applied domains such as health (e.g., Garcia-Retamero & Cokely, 2011; Garcia-Retamero & Galesic, 2010; Peters et al., 2011; Rothman & Salovey, 1997) and finance (Kirchler et al, 2005; Weber et al., 2000). Our findings highlight a promising direction for the strategic application of question framing for increased safety in various domains of applied risk perception and communication. The aim of public risk management is to optimize the decision matrix to enable users to maximize their personal enjoyment and benefit while minimizing both individual and collective public risk. Critically, as in avalanche terrain, one wants to minimize the probability that a “go” decision is made under objectively “no-go” conditions. We do not believe that the framing of risk judgment questions alone will be sufficient to ensure safe behavior among all decision makers and or in all risky domains. It is no substitute for the availability of valid evidence of the objective risk, and the necessary knowledge and experience to understand and apply that information. However, the adoption of a procedure strategy such as that afforded by framing risk judgment questions may boost an individual’s overall competency for risk judgments or behavioral decisions. Various disciplines can conceivably harness the questions framing effect to make desired judgments and behaviors more likely. Risk management strategies, tools and education should recognize and account for this effect, and leverage these emergent findings to reduce the potential for accidents and fatalities.

Conclusion

The present research makes several contributions to the existing literature on framing effects. First, our research establishes the direction of the framing effect when a risk judgment is

framed in terms of safety or danger. Risk judgments framed in terms of safety (*How safe is it?*) result in more cautious, conservative judgments than when framed in terms of danger (*How dangerous is it?*). Second, uncertainty was not a requirement for that effect. There was a framing effect when judging risk under varying degrees of uncertainty, be it under conditions of objective safety, uncertainty, or danger. These findings suggest that the question frame directed attention in a way that guided selective evidence sampling, rather than indicating a valence-consistent or communication-driven framing effect. Finally, our findings demonstrate the indirect influence of the question frame on behavior intention. The adoption of a procedure strategy such as that afforded by framing risk judgment questions can boost people's natural decision making competencies in order to ensure safer risk perceptions and behavior. These findings have the potential to inform the development of policies and practices that harness question framing in domains of applied risk perception and risk communication.

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Should We Judge Danger or Safety in Avalanche Terrain?

Matthew B Stephensen, Markus Landrø, Jordy Hendriks

MINDY AND KELSEY HIKE UP THE VALLEY, weaving their way through thinning forest and steepening terrain to the top of a small rise where they stop. They are entering avalanche terrain and it is time to decide if they should continue on their planned route. Ahead of them is a long, steep climb up a broad face to reach the more gradual ridgeline that they intend to follow to the summit. They dig a snow pit but do not find any sign of the persistent weak layer mentioned in the regional avalanche forecast. The snowfall has been light but steady and the winds variable over the past 48 hours. Although no cornices are visible on the ridgeline, spindrift indicates the wind is starting to pick up. They have not seen any obvious avalanche clues. They stand there, pondering the uncertainty of the conditions.

Kelsey breaks the silence: "It looks good. I don't believe it's dangerous," she remarks. "I think we should continue."

Mindy wrinkles her brow: "Really? It doesn't look safe to me," she counters. "We should turn back."

Why might two recreationists with similar training, competency, and experience make opposite decisions when judging the same evidence about the conditions? To try to answer that question, we must consider the cognitive mechanisms involved in the decision making process.

QUESTION FRAMING

When we judge risk, we are judging the attribute of an object, action, or situation. Attributes are commonly understood in terms of their multiple dimensions. For example, the attribute 'speed' is often understood in terms of two dimensions: fast and slow. Those two dimensions are like two sides of a coin, distinct but indivisible. They provide opposing but complementary perspectives.

We tend to focus on a single dimension when making a judgment. For example, when judging speed, we commonly ask, "Is it fast?" or alternatively, "Is it slow?" rather than formulating a judgment using both dimensions. It is a natural process of language and thought to frame judgments with only one qualitative dimension of the judged attribute.

Similarly, when moving through avalanche terrain, we might also use a single qualitative dimension to frame avalanche risk judgements such as "How safe are the conditions?" or "How dangerous are the conditions?"

What we wanted to know is: does the choice of frame have an effect on perceived risk and behavioural decisions? If so, can we strategically employ that frame to increase the likelihood of more cautious, conservative judgments and decisions in avalanche terrain?

Our research found that frames influence perceived avalanche risk and behaviour intention. In a series of studies, we examined how backcountry skiers judged hypothetical scenarios of skiing in avalanche terrain (presented in the form of a photo and basic regional avalanche advisory information) when asked to judge *safety* or *danger*. We found that risk judgments framed in terms of safety ("How safe is it?") resulted in more cautious, conservative judgments and a lower likelihood of skiing than judgments framed in terms of danger ("How dangerous is it?").

This happens because the frames "safe" or "dangerous" direct the decision maker's attention during the judgement process. Judging "How safe is it?" defines *safe* as the reference point for the risk judgment. This focuses attention on finding and evaluating evidence of safety. Under conditions of uncertainty when there is no definitive indication of safety, such as in our example with Mindy and Kelsey, safety is judged as lower due to the lack of supporting evidence. Lower safety implies the unspecified opposite dimension—higher danger—resulting in a lower likelihood of deciding to ski a slope.

Conversely, when judging the danger ("How dangerous is it?") of the same scenarios, danger is judged to be lower (and consequently safety is perceived to be higher) because of the lack of definitive evidence of danger, resulting in a higher likelihood of deciding to ski a slope.

By asking backcountry travellers to judge how safe the conditions are, we exploit the lack of definitive evidence of safety to actually promote more cautious judgements and behaviour. Failing to find evidence of danger should not be considered an indication of safety. Yet failing to find evidence of safety must be considered an indication that it is not safe.

STRATEGICALLY FRAMING RISK PERCEPTION IN AVALANCHE TERRAIN

Decision making in an avalanche terrain is seldom free of uncertainty. How we formulate risk judgments can have a real impact on how people perceive risk and, ultimately, when and how they decide to act. How then might we harness the power of framing in the avalanche industry?

The use of framing to promote specific judgments and decisions is an established practice in fields such as media and marketing. We can similarly employ framing to promote safer risk perceptions and behaviour in avalanche terrain. Guides, avalanche warning services, and avalanche safety educators have substantial control over the phrasing of questions about the risks they assess for a backcountry trip.

Framing can be systematically applied to numerous risk judgments and decisions, whether it be deciding to ski a specific line or deciding to open or close specific terrain.

Communication between members of a group travelling in avalanche terrain could be positively impacted by increased awareness of the framing effect. How information and questions are framed could influence other group members' perceptions of the current risk and the decisions made or communicated between members of the group. For example, when a guide or group leader notices changes in the conditions, they can advantageously frame their question to the group to focus attention on those changes in relation to the basis for any earlier judgments of safety.

Let's say the basis for the decision to ascend a slope is that the old snowpack is stable with fresh, non-wind loaded powder snow on top. After some climbing, the snow surface shows signs of wind effect. Focusing on establishing safety forces the group to reassess the conditions relative to the previous evidence of safety (non-wind affected snow) and the possibility that conditions have changed (evidence of wind slabs). The group must evaluate if the evidence previously indicating safety is no longer present or if new evidence of safety is available. The group must therefore reconsider its arguments and possibly change its decision.

Asking "How safe is this slope?" increases attention paid towards evidence of safety—not just the absence of signs of danger—making the group more critically aware of any changes in conditions while guiding the decision toward a more conservative, transparent, and possibly safer outcome.

Framing risk judgments alone is insufficient to ensure safer behaviour among all backcountry recreationists. It is no substitute for the training, knowledge, and experience to understand and apply information about the conditions. Nonetheless, adopting a strategy for framing risk judgments can increase the likelihood of more cautious, conservative behaviour.

There is often so much uncertainty when making decisions in avalanche terrain that we must utilize any tool or method that can help, even if just a little. Critically, one wants to minimize the chance that a "go" decision is made under objectively "no-go" conditions. If the way a question is framed influences

the decision of whether to ride or not, then avalanche risk management strategies, tools, and education should recognize and account for this effect and incorporate framing risk judgments into routine practices to reduce the potential for avalanche accidents.

The next time there is uncertainty about the current avalanche conditions, stop and think about the way you frame the question, and how it could influence your decision. Think about how you might be able to harness framing to provide that extra margin of safety in times of uncertainty.

A peer-reviewed article that provides a detailed account of our research on question framing is forthcoming in the *Journal of Experimental Psychology: Applied*. That article can be accessed at doi.org/10.1037/xap0000354. ■





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Wie entscheiden Experten im Lawinengelände?



Markus Landrø hat sich für seine Linie am Nibbi (Hemsedal, Norwegen) entschieden. Foto: Sindre Thoresen Lønnes

Bei Skitouren im Lawinengelände ist es (überlebens-) wichtig, die Lawinengefahr richtig zu beurteilen und dann gute Entscheidungen zu treffen. Es gibt verschiedene Grundlagen – in diesem Text auch kurz als Strategien bezeichnet –, die uns dabei helfen sollen, die bestmögliche Entscheidung zu treffen.

Es gibt sehr gut beschriebene und exakt geregelte Ansätze, aber auch weniger formale Strategien. In mehreren Ländern gibt es nationale Fachforen oder Institutionen, wie z.B. das Kernteam Lawinenausbildung (KAT) in der Schweiz oder die Canadian Avalanche Association (CAA) in Kanada, die solche Strategien evaluieren, empfehlen und in einigen Fällen auch herausgeben. Weitere Organisationen, die bestimmend dafür sind, welche Strategien unterrichtet werden, sind die nationalen Bergführerverbände und Alpenvereine.



von Markus Landrø und Gerit Pfuhl

In unserer Arbeit haben wir die am häufigsten verwendeten Strategien in Europa und Nordamerika untersucht. Sie sind in zahlreichen Büchern und Artikeln bestens beschrieben, sodass wir auf eine Vorstellung oder einen Vergleich an dieser Stelle verzichten.

Die zehn Strategien in unserer Studie sind:

- 3x3
- Reduktionsmethode
- SnowCard
- Stop or Go
- NivoTest
- Grafische Reduktionsmethode
- Systematische Schneedeckendiagnose
- Avaluator 2.0
- ALPTRUTH (Kanada)
- After Ski Methode (Norwegen)

In diesen zehn Strategien basieren die Entscheidungen typischerweise auf einer Beurteilung von vier Arten von Faktoren:

1. physikalische Faktoren (z.B. Hangneigung)
2. regionale Gefahrenstufe des Lawinewarndienstes
3. im Gelände beobachtete Instabilitätserscheinungen, d.h. Alarmzeichen (z.B. kürzlich abgegangene Lawinen, Wumm-Geräusche, ...)
4. soziale Faktoren (z.B. Gruppengröße, ...)

Für jede der zehn Strategien haben wir alle jeweils relevanten Faktoren identifiziert und konnten dabei über 50 unterschiedliche nachweisen. Viele davon werden von mehreren Ansätzen geteilt, aber die Strategien unterscheiden sich zum Teil in Art, Bedeutung und Anzahl der einbezogenen Faktoren.

Alle Faktoren können thematisch gruppiert werden in Faktoren für ...

- die Schnee- und Lawinenbildung
- die Schneedeckenuntersuchungen
- Stabilitätstests
- den Lawinenlagebericht
- die Gruppe
- das Gruppenmanagement
- das Gelände

Beispiele für Faktoren, die zum Thema Gelände gehören, sind: Messen von Steilheit in 5°-Intervallen ab 30° und die Unterscheidung zwischen Lawinen- und nicht Lawinengelände. Beispiele für Faktoren, die zum Thema Gruppenmanagement gehören, sind: 30 m Entlastungsabstand im Aufstieg und Einzelfahren ab 35° in der Abfahrt.



Fragestellung

Wir wollten wissen, ob Experten diese Strategien kennen und verwenden. Wir wollten auch wissen, ob sie in den verschiedenen Phasen einer Tour im Gelände tatsächlich auch dieselben Faktoren be-

urteilen und für wichtig halten, die in den Strategien gelehrt und angewendet werden. Im Rahmen einer Online-Umfrage haben wir gezielt Experten angeschrieben. Diese, d.h. die Teilnehmer unserer Studie, sind sowohl Bergführer, Lawinenprognostiker und Lawinenforscher, als auch professionelle Skifahrer und Snowboarder. Diese beiden Expertengruppen schienen uns deswegen interessant, da sie einen anderen Ansatz in der Lawinenbeurteilung und Entscheidungsfindung haben könnten.

Die Umfrage wurde auf Englisch, Deutsch und Norwegisch durchgeführt, wodurch wir Antworten von Expertengruppen aus verschiedenen Ländern erhielten, die sich in ihren Traditionen und Ansätzen zur Entscheidungsfindung im Lawinengelände unterscheiden. Die Umfrage wurde nicht auf Französisch oder Italienisch übersetzt und deshalb auch nicht an Experten in diesen Ländern verteilt. Dies ist in erster Linie auf die begrenzte Übersetzungskapazität zurückzuführen, deshalb konnten auch andere relevante Länder und deren Experten nicht berücksichtigt werden.

Zuerst haben wir „unsere“ Experten zur Anwendung und Bedeutung aller von uns identifizierten Faktoren befragt, bevor wir Fragen zur Kenntnis und Anwendung der zehn Strategien stellten. Auf diese Weise mussten die Experten darüber nachdenken, welche Faktoren sie tatsächlich in ihrer Entscheidungsfindung verwenden und welche in den verschiedenen Phasen einer Tour wichtig sind – sie konnten sich also nicht einfach auf die Faktoren berufen, die fixer Bestandteil einer Strategie sind.



Ergebnisse

Im Folgenden präsentieren wir einen Auszug aus unseren Umfrageergebnissen. Wir konzentrieren uns dabei auf den Teil über „Wissen und Anwendung bestehender Strategien“ und auf den einen Faktor, der in den meisten Strategien entscheidend ist: die Gefahrenstufe.

Die Experten

Im Zeitraum von drei Monaten, die unsere Online-Studie lief, beantworteten 100 Experten den Fragebogen:

- Die Experten kamen zu gleichen Teilen aus Skandinavien, dem deutschsprachigen Teil der Alpen und Nordamerika.
- Die Mehrheit waren Männer, 10 % waren Frauen.
- Im Durchschnitt hatten die befragten Experten 28 Jahre Erfahrung mit Skitouren und verbrachten pro Saison 50 Tage auf Skitouren.
- Die meisten Teilnehmer hatten deutlich mehr, einige wenige jedoch weniger Tourentage.
- Pro Saison waren im Schnitt 73 % dieser Skitage im Lawinengelände.

Analytisches und implizites Wissen

Die oben erwähnten zehn Strategien lassen sich in analytische/wissensbasierte und probabilistische/regelbasierte Ansätze unterteilen. Alle Strategien in unserer Studie haben Komponenten aus beiden Ansätzen, die im Entscheidungsprozess gemeinsam genutzt werden sollten. Weiterhin haben wir auch angegebene Entscheidungen basierend auf Intuition mit einbezogen, auch wenn diese kein Bestandteil einer dieser Strategien sind.

Die Zahlen für die anderen Strategien sind klein und erlauben es nicht, eindeutige Rückschlüsse zu ziehen. Unsere Ergebnisse deuten jedoch darauf hin, dass die Strategien vorrangig in Ausbildungskursen zur Anwendung kommen.

■ Von den befragten Experten gaben 89 % an, dass sie eine wissensbasierte, analytische Entscheidungsfindung anwenden, bei der detaillierte Beobachtungen und eine sorgfältige Beurteilung der Faktoren unerlässlich sind.

■ Weiterhin sagten die Experten aber auch, dass sie sich auf ihre Intuition verlassen: 79 % vertrauen ihrer Intuition, die sie als Bauchgefühl und basierend auf langjähriger Erfahrung beschreiben.

■ Eine kleinere Gruppe (32 %) gab an, das Risiko zu kalkulieren: Sie berechnen die Wahrscheinlichkeit von Lawinen und potenziellen Folgen.

■ 39 % gaben an, sich situationsabhängig zu entscheiden: In vertrauten Situationen wird eine Faustregel verwendet, aber falls die Situation eher unbekannt ist, verwenden sie analytische Methoden.

■ 16 % gaben an, sich auf die probabilistische/regelbasierte Entscheidungsfindung zu stützen.

Kenntnis und Anwendung von vorhandenen Strategien

Wir haben die Experten gefragt, mit welcher der vorhandenen Strategien sie vertraut sind, wobei Mehrfachnennungen möglich waren (Abb. 1):

■ Das 3x3 von Munter war zu 68 % bekannt. Diese Methode ist ein integrierter Bestandteil der Reduktionsmethode (RM) – auch zu 68 % bekannt – und wird in Kombination mit mehreren anderen Strategien gelehrt.

■ Der kanadische Avaluator 2.0 (A2.0) ist bei 61 % der befragten Experten bekannt.

■ Für die anderen Strategien beträgt der Bekanntheitsgrad: Grafische Reduktionsmethode (GRM) 35 %, Snow-Card (SC) 42 %; Stop or Go (SoG) 43 % und Systematische Schneedeckendiagnose (SSD) 44 %.

■ Die After-Ski-Methode (ASM) mit 24 % sowie NivoTest (NT) und AlpTruth (AT) mit jeweils 27 % waren am wenigsten bekannt, was sich durch die sehr begrenzte Anwendung außerhalb ihrer Herkunftsländer (Norwegen, Schweiz und Kanada) erklärt. 16% listeten weitere Strategien und Ansätze auf, die nicht in dieser Studie enthalten sind. Nur ein Experte sagte, dass er keine der Strategien kannte.

Abb. 1 zeigt den Unterschied zwischen der Kenntnis und der Anwendung der Strategien. Bemerkenswert ist, dass die SSD von einem hohen Anteil der Personen, die sie kennen, auch tatsächlich genutzt wird (77 % der 44 Personen) – keine andere Strategie wird so häufig von den befragten Experten angewendet.

Die Zahlen für die anderen Strategien sind klein und erlauben es nicht, eindeutige Rückschlüsse zu ziehen. Unsere Ergebnisse deuten jedoch darauf hin, dass die Strategien vorrangig in Ausbildungskursen zur Anwendung kommen.

Tatsächlich gehören viele unserer befragten Experten einer Gruppe an, die typischerweise solche „Lawinenkurse“ unterrichten (z.B. Bergführer, Skiführer). Aber nur sehr wenige vermitteln dort auch eine der Strategien - mit Ausnahme jener (22 von 34), welche die SSD verwenden. Diese begrenzte Vermittlung der Strategien in Ausbildungen ist auffällig, insbesondere da mehrere davon speziell für Anfänger entwickelt wurden. Die meisten der Strategien sind hauptsächlich probabilistisch/regelbasiert und gelten als gut geeignet für

Abb. 1 Kenntnis und Anwendung der Strategien in absoluten Zahlen (von 100 Befragten) und Anwendung in relativen Zahlen. Mehrere Antworten waren möglich.

Strategie	kennen (n=100)	verwenden davon (%)
3 x 3	68	25 (37 %)
Reduktionsmethode	68	9 (13 %)
Avaluator 2.0	61	10 (16 %)
Systematische Schneedeckendiagnose	44	34 (77 %)
Stop or Go	43	5 (12 %)
Snow Card	42	3 (7 %)
Grafische Reduktionsmethode	35	12 (34 %)
AlpTruth	27	3 (11 %)
NivoTest	27	1 (4 %)
After Ski Method	24	4 (17 %)

Einsteiger, verlangen sie doch vergleichsweise wenig Wissen oder Können für die korrekte Anwendung und sind dankbar zu unterrichten. Die SSD hingegen ist hauptsächlich analytisch/wissensbasiert und gilt traditionell als weniger geeignet für Anfänger.

Verwendung von Strategien in verschiedenen Phasen einer Skitour

Auch wenn man das 3x3 von Munter nicht benutzt, ist es üblich, eine Skitour in verschiedene Phasen aufzuteilen. Diese können als Entscheidungsprozess verstanden werden, der von der Tourenplanung (regional) über die Routenwahl (lokal) bis hin zur Einzelhangentscheidung (zonal) reicht. Die Idee dabei ist, dass es nützlich ist, die Lawinenbeurteilung und den Entscheidungsprozess mehrmals durchzuführen. Dies bietet dann mehrere Möglichkeiten durchdachte Entscheidungen zu treffen und gefasste Pläne durch neue Informationen zu ändern. Somit reduzieren wir das Risiko einer Lawinenauslösung. Laut Munter ist eine Kombination aus seinem 3x3 und RM eine Voraussetzung, um das gewünschte Risikoniveau zu erreichen. 23 Experten bestätigten, dass sie das 3x3 bei der Tourenplanung verwenden, aber die Wichtigkeit in den weiteren Phasen abnimmt. Mit Ausnahme von 3x3 und SSD ist die Verwendung von Strategien in verschiedenen Phasen sehr begrenzt. Unsere Ergebnisse deuten jedoch darauf hin, dass diejenigen, die A2.0 und GRM nutzen, sie bei der Tourenplanung und Routenwahl verwenden. Im Gegensatz zu den anderen Strategien erhöht sich der Einsatz der SSD von acht Experten in der Tourenplanung auf 26 in der Routenwahl und 29 im Einzelhang entscheidend. Dies ist verständlich, da die in der SSD enthaltenen Faktoren im Gelände beobachtet und beurteilt werden müssen, während die anderen Strategien Faktoren beinhalten, die bereits vor Beginn einer Skitour ermittelt und verwendet werden können.

Ist eine Strategie oder ein Faktor entscheidend, relevant oder eher unbedeutend?

Eine unserer Fragen war: „Wie wichtig/nützlich sind diese Methoden in der Praxis für Deine Entscheidung am Einzelhang?“

Diese Frage stellten wir, nachdem die analytischen oder probabilistischen Ansätze befragt wurden, und hier zeigte sich, dass Experten sich auf ihre Intuition verlassen. Diejenigen, die SSD kennen, vertrauen ihr auch am Einzelhang.

Gründe für oder gegen die Nutzung der Strategien

36 % gaben an, dass die Strategien „einen anderen Ansatz verwenden“ und 29 % gaben an, dass die Strategien „einer Struktur folgen, die nicht zu meiner Art von Entscheidungsfindung passt“.

Warum verwenden Experten die Strategien nicht? Fast 1/3 gab an, dass die Strategien die Entwicklung und das Lernen einschränken (29 %) und den Benutzer vom eigenen Denken abhalten (18 %). Neben der technischen Beherrschung von Ski oder Snowboard erfordert das Skitourengehen weitere Fertigkeiten, wie z.B. Orientierung, sich warm und trocken zu halten, usw. und nur ein Teil davon ist eben auch die Fähigkeit zur Beurteilung der Lawinengefahr. 14 Experten sagten, dass die Nutzung der Strategien zu kompliziert ist, wenn sie draußen in den Bergen sind und es schwierig ist, die verwendeten Faktoren zu beurteilen.

Dies stellt dann allerdings in Frage, inwiefern diese Strategien nun für Anfänger geeignet sind, die sich neben der Lawinengefahrenbeurteilung meist auch noch die zahlreichen anderen notwendigen Fähigkeiten zum Bewegen im winterlichen Gelände aneignen müssen. Noch beunruhigender war, dass 14 Experten angaben, dass sie nicht an die den Strategien zugrunde liegenden Statistiken glauben. Fünf behaupteten, dass Strategien nicht zu funktionieren scheinen, neun, dass Strategien die falschen Faktoren kombinieren und acht, dass sie auf den falschen Faktoren basieren.

Sechs der Experten stimmten der Aussage zu „Zu oft sagt die Methode Nein, und die Leute fahren dann trotzdem und nichts passiert“, was zeigt, dass die Strategien den Anwender zu stark einschränken. Dies deutet darauf hin, dass diese Experten der Meinung sind, dass die Genauigkeit der Strategien begrenzt oder dass die Sicherheitsmarge zu groß ist.

Natürlich haben wir auch gefragt, warum „ihre“ benutzte Strategie wichtig ist. Hier antworten viele:

- Es hilft, aktiv in eine bestimmte Denkweise einzusteigen.
 - Es hilft, den Entscheidungsprozess zu strukturieren.
 - Es verhindert, dass wichtige Informationen übersehen werden.
- Es unterstützt Intuition und Bauchgefühl.

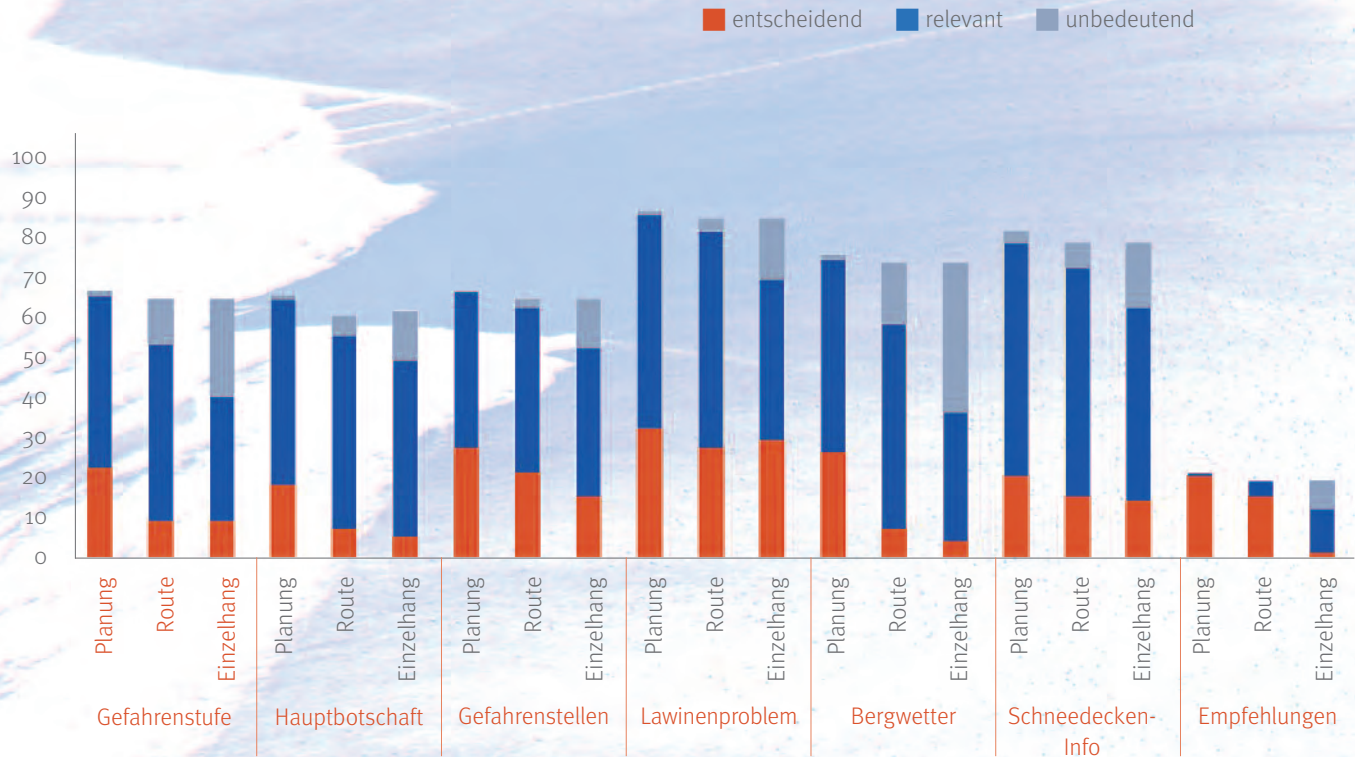
Es ist also deutlich, dass auch Experten etwas schätzen und verwenden, was Rahmen und Struktur bietet und somit den Entscheidungsfindungsprozess unterstützt.

Der Lawinenlagebericht und die Gefahrenstufe.

Bei der Auswahl des Tourenzieles oder bei der Planung einer Skitour ist ein Lawinenlagebericht eine nützliche Informationsquelle. Nur 2 % der Experten gaben an, nie die Informationen aus einem Lawinenlagebericht zu nutzen. 63 % benutzen den Bericht immer und 35 % manchmal. Der Lawinenlagebericht wird hauptsächlich bei der Planung verwendet (50 %), weniger bei der Routenwahl (30 %) und bei Entscheidungen am Einzelhang (20 %).

Ein Lawinenlagebericht besteht aus mehreren Elementen. Wir haben die Experten gefragt, welche Elemente sie in verschiedenen Phasen

Abb. 2 Wichtigkeit der Elemente im Lawinenlagebericht. Der Lawinenlagebericht mit seinen Elementen „Lawinenproblem“ und „Gefahrenbeschreibung und Schneedeckeninfo“ ist für die 100 befragten Experten wichtiger als die Gefahrenstufe.



verwenden und welche Bedeutung diese Elemente haben (Abb. 2). Die Gefahrenstufe gilt traditionell als das wichtigste Element in einem Lawinenlagebericht, sowohl für die weltweiten Lawinenwarndienste als auch für die European Avalanche Warning Services (EAWS). Mit Ausnahme von NT und SSD ist die Gefahrenstufe entweder ein gleichwertiger (AT und A2.0) oder der prominenteste Faktor und Ausgangspunkt im Entscheidungsprozess.

Es hat sich allerdings gezeigt, dass für viele Experten die Verwendung und die Bedeutung des Faktors „Gefahrenstufe“ in den verschiedenen Phasen einer Skitour abnimmt: 1/3 gab an, dass die Gefahrenstufe für Entscheidungen am Einzelhang unbedeutend ist.

Dies lässt sich einerseits durch das Gefahrenstufen-Konzept selbst, d.h. die Art und Weise, wie die Gefahrenstufe bestimmt wird und andererseits durch ihre Verwendung in einigen Strategien nachvollziehbar erklären – und ist in der Literatur der letzten Jahre nachzulesen:

■ Die Gefahrenstufe ist weder für kleinräumige oder hängespezifische Beschreibungen geeignet, noch wurde sie zu diesem Zweck entwickelt (Nairz, 2010).

- In Wirklichkeit ändert sich das Gefahrenniveau kontinuierlich, nicht schrittweise wie auf der Skala. Die Schritte implizieren eine bestimmte Gefahrenstufenbandbreite (Mitterer, 2015).
- Fehlende Einheitlichkeit in der Bestimmung der Gefahrenstufe (Müller, 2016).
- Unsicherheit im Zusammenhang mit dem Lawinenlagebericht (Prognose) und systematischen Verifikationsverfahren bezüglich Gefahrenstufe (Schweizer, 2010; Schweizer, Kronholm, & Wiesinger, 2003; Techel, Dürr, Schweizer, 2016).
- Da uns die Gesamtzahl der Skitourengeher fehlt, ist die Verwendung von einer Gefahrenstufe als ein zentraler Faktor in der Risikoberechnung zusammen mit Lawinenunfalldaten problematisch (Kronthaler, 2001; McCammon & Hägeli, 2005).
- Bei der unfallbasierten Risikoberechnung werden nicht alle Fälle berücksichtigt, in denen ein Experte aufgrund ihrer/seiner Lawinenbeurteilung einen bestimmten Hang nicht befahren hat. In einer Kalkulation hätte dies als Ereignis zählen sollen.
- Das Lawinenproblem hat keinen direkten Einfluss auf die Bestimmung von Gefahrenstufen, z.B. Berechnungen von Techel und Winkler (2015) zeigen, dass das relative Risiko bei gleicher Gefahrenstufe in Situationen mit Altschnee-Schichten 50 % höher ist als bei anderen Lawinenproblemen.

Unsere Ergebnisse signalisieren, dass wir in Zukunft weniger Wert auf die Gefahrenstufe legen sollten, sondern mehr auf das aktuelle Lawinenproblem und die Schneedeckeninformationen. Diese Einschätzung wird durch eine aktuelle Studie über die Kommunikationswirksamkeit von Lawinenwarnungen (Engeset et al., 2018) untermauert, an der auch Anfänger und weniger qualifizierte Anwender teilnahmen.

S Schlussfolgerung

Die Experten kennen die Strategien, wenden sie aber nicht konsequent an. Eine Ausnahme bildet hier die Kenntnis und Anwendung der Systematischen Schneedeckendiagnose.

Nur sehr wenige der Experten verwenden einen probabilistischen Ansatz, bei dem das Lawinenrisiko aus Kombinationen von Wahrscheinlichkeiten berechnet wird. Die Mehrheit der Experten wenden bei ihren Entscheidungen einen analytischen, wissensbasierten Ansatz an.

Experten beobachten und beurteilen Alarmsignale und sind selbst aktiv bei der Suche und Verifizierung der aktuellen Lawinenprobleme. Sie führen z.B. Stabilitätstests durch, um ein Problem zu erfassen bzw. zu beobachten und versuchen dabei zu analysieren, wie wahrscheinlich eine Lawine ist, welche Zusatzlast notwendig und mit welcher Lawinengröße zu rechnen ist.

Die Ausbildung von Anfängern sollte möglicherweise nicht allein durch Vereinfachungen und Regeln erfolgen. Die Betonung der Komplexität der Lawinenprobleme und der Umgang mit diesen sollte frühzeitig gelehrt werden. Darüber hinaus sollten es zukünftige Strategien dem Benutzer ermöglichen, mit seiner Erfahrung zu wachsen

und eine Weiterentwicklung nicht behindern. Vielmehr sollten sie den Übergang vom Anfänger über den Könnler bis zum Experten unterstützen und fördern.

Alle Strategien erfordern neue Beurteilungsdurchgänge, wenn man neue Informationen – wie z.B. Alarmsignale – erhält. Außer der Systematischen Schneedeckendiagnose bieten die Strategien keine Struktur, wie man solche klaren Informationen wie frische Lawinen oder Wumm-Geräusche vollumfänglich analysiert und interpretiert, und weniger offensichtliche Informationen, wie z.B. Altschnee-Schichten, werden leicht übersehen.

Die Gefahrenstufe ist ein guter Indikator für die Verhältnisse, denen man mit hoher Wahrscheinlichkeit im Gelände begegnen wird. Der Lawinenlagebericht enthält jedoch weit mehr als nur die Gefahrenstufe. Die Information über Lawinenprobleme und die Schneedecke sollten in zukünftigen Strategien eine größere Rolle spielen, um ihr Ausbildungs- und Sicherheitspotenzial zu nutzen.

Anerkennung

Wir bedanken uns für die Zeit und den Aufwand, den die befragten Experten für unsere Befragung aufgewendet haben. Wir danken auch allen, die zur Entwicklung von Strategien beigetragen haben, um uns alle bei der Entscheidung zu helfen, ob wir in einen Hang einfahren sollen – oder besser nicht.

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