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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 Lütschg, 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), ALPTRUTh (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, 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

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

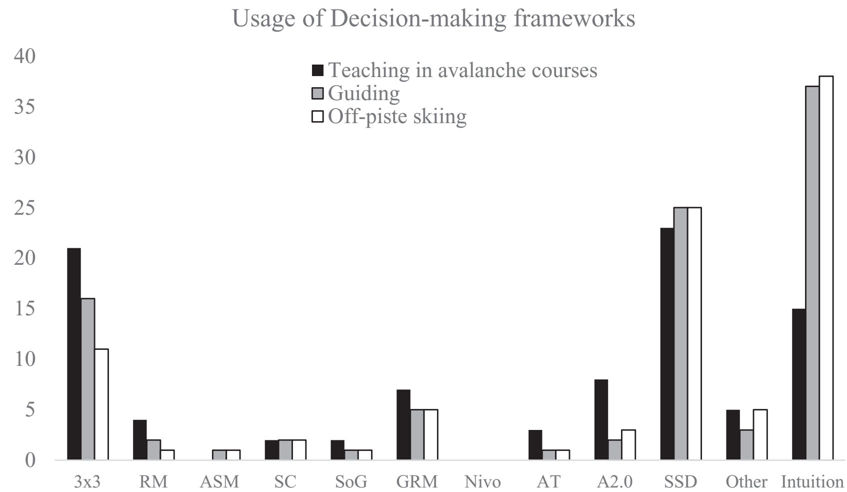

Fig. 1. Experts' stating for what they use the DMFs. Two experts wrote in the text field for other DMF: "Canadian joint decision making" and MB Achtung Lawinen, respectively.

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	78
	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
Avalanche forecast	Danger level	RM, ASM, SC, SoG, GRM, A2.0, AT	66
	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	28
	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 backcountry, (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 to 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 use 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 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 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

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

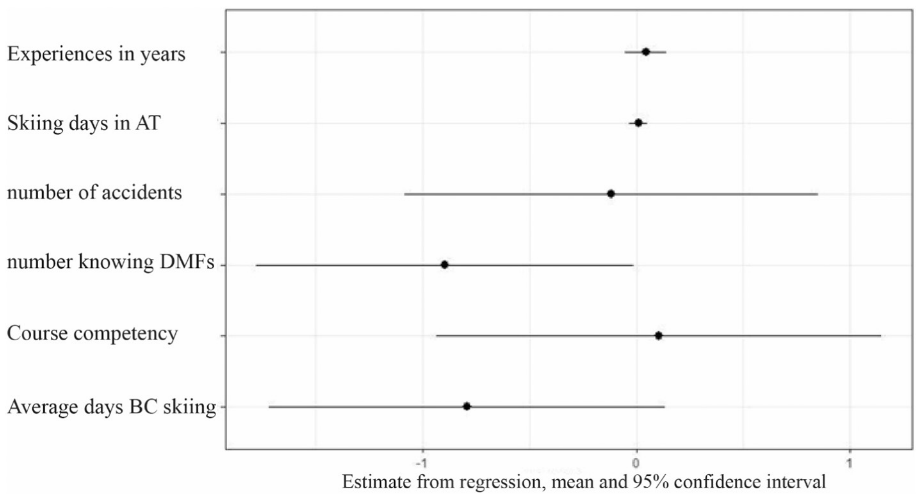

Fig. 2. Standardized coefficients and 95% confidence of the six predictors for the number of factors an expert uses.

(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 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

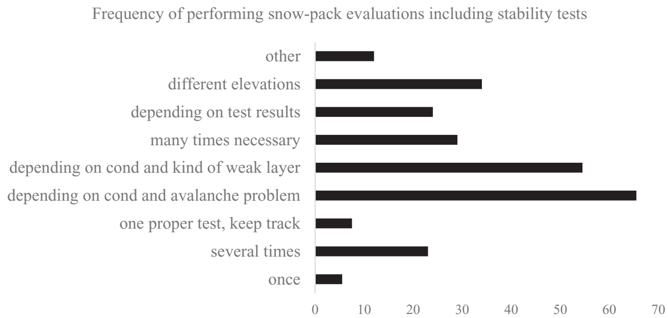

Fig. 3. Frequency of performing snowpack evaluations and stability tests (frequencies are averaged from the responses to "how often do you perform a) snowpack evaluations and b) stability test". Cond = condition.

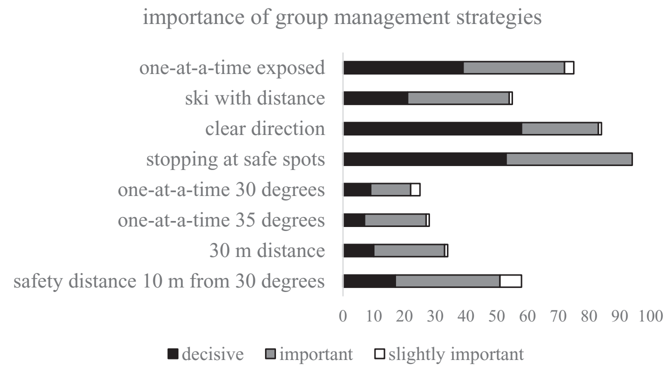

Fig. 4. Group management factors.

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 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 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

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.

Acknowledgement

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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