INSIGHTS ON HOW AVALANCHE FORECAST USERS COMBINE DANGER RATINGS WITH STEEPNESS TO ASSESS THE AVALANCHE RISK OF INDIVIDUAL SLOPES DURING TRIP PLANNING

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ABSTRACT: Several recent studies have examined avalanche forecast users' ability to understand the provided hazard information, but they have so far not evaluated how users combine the information with additional avalanche knowledge to assess the severity of the conditions on individual slopes, which is a critical skill for the effective application of the forecast information during trip planning. We conducted an online experiment with members of the Euregio and Swiss avalanche forecast research panels where participants were presented with a series of hypothetical avalanche forecasts and asked to rank four slopes according to their avalanche risk. Each slope was characterized by a different combination of aspect, elevation, and slope steepness, which was described using the standard qualitative terms defined by the European Avalanche Warning Services. Our survey also included several questions examining participants' understanding of the qualitative steepness terms. Our revealed that only 16% of the sample provided the "Graphic Reduction Method" solution to the slope tanking exercise, while 55% used a sequential approach where they first split the slopes according to the provided danger rating and then ranked them according to steepness. The responses to the questions on the steepness terms showed that approximately half of our participants believe that 'extreme terrain' starts at inclines that are steeper than the 40° threshold defined by EAWS. This means that they potentially underestimate the severity of the terrain described in forecasts. We derive several management implications for avalanche warning services from our results.

KEYWORDS: Risk communication, avalanche forecast users, survey study

1. INTRODUCTION

It is well known in the risk communication community that an in-depth understand of the characteristics, needs, and existing practices of the audience is an important prerequisite for the development of effective risk communication messages (e.g., Balog-Way et al., 2020; Eastern Research Group and NOAA Social Science Committee, 2019; Lundgren and McMakin, 2018). Having a detailed understanding of how backcountry recreationists access, comprehend and apply avalanche safety products is therefore essential for avalanche warning services and avalanche safety educators to assess the effectiveness of their products and services, make informed decisions about how to improve them and develop new ones.

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To provide avalanche warning services with the necessary insight, a body of research has started to emerge that examines recreationists' perception of the avalanche forecast information and their ability to understand and apply it for trip planning. Example studies include Winkler and Techel (2014), Engeset et al. (2018), Margalef et al. (2018), St. Clair et al. (2021), Finn (2020), Fisher et al. (2021), Engeset et al. (2022); Fisher et al. (2022a), Fisher et al. (2022b), and Morgan et al. (2023). Most of these studies were online surveys with large samples of forecast users, and several of them included hypothetical assessment tasks designed to examine recreationists' use of the avalanche hazard information. Finn (2020), for example, asked participants to identify whether avalanche problems described in a forecast were present on different slopes on an idealized landscape, and Fisher et al. (2021) asked participants to assess and rank a series of routes based on their exposure to the described avalanche hazard. However, so far, none of these study have evaluated how recreationists combine the hazard information provided in avalanche forecasts with additional avalanche knowledge to assess the severity of conditions on individual slopes, which is a critical skill for the effective application of forecast information during trip planning.

To examine this process, we conducted an online survey where participants were presented with a series of hypothetical avalanche forecasts and asked to rank four slopes of different locations (aspect, elevation) and steepness according to their avalanche risk. The results of this study provide insights about how participants approach the task and what type of information they pay attention to.

2. METHODS

The analysis presented in this paper draws from a large online survey conducted by the Simon Fraser University Avalanche Research Program in collaboration with the Euregio (Tyrol, South Tyrol, and Trentino) and Swiss avalanche warning services. All recreational members of the avalanche forecast user research panels of the two warning services (Haegeli et al., 2023) were invited to participate in the survey, which collected data from March 30 to April 30, 2022. While all participants saw the same questions, the survey design and the wording of certain questions was localized (i.e., warning service specific). The survey was available in German, Italian, French, and English.

2.1 Question design

Slope ranking exercise

The main survey question relevant for the present analysis was a slope ranking exercise where participants were presented with an avalanche forecast and four slopes identified on an idealized mountainscape (Figure 1). Six different avalanche forecasts were pulled from the archives of the warning services to create a set of scenarios that differed systematically in the number and types of avalanche problems, the extent of the avalanche prone locations, and the danger ratings in the avalanche prone locations and the surrounding areas (Table 1).

Table 1: Avalanche forecast scenarios.

ID	*Aval. prob.*	*Avalanche prone locations*	*Danger ratings*
1	new	All asp., > 2000 m	Cons – Mod
2	old, new	All asp., > 2000 m	Cons – Mod
3[a]	wind	NW-N-NE, > 2000 m	Mod – Low
4	old, new	W-N-E, > 2200 m	Cons – Mod
5	wet	E-S-W, < 2600 m	Cons – Low
6	old, new	W-N-E, > 2000 m	High – Mod

[a] Scenario shown in Figure 1.

The accompanying four slopes varied by elevation and aspect (both shown on the map) and steepness, which was indicated with the qualitative steepness terms defined by the European Avalanche Warning Services (n.d.): *moderately steep* (< 30°), *steep* (≥ 30°), *very steep* (≥ 35°), and *extremely steep* (≥ 40°). Each scenario had two moderately steep slopes and two very steep slopes with one of each being inside and outside of the avalanche prone locations. This created a unique combination of hazard and terrain characteristics for each slope.

The survey presented each participant with two scenarios in a format that mimicked the look and feel of the avalanche forecast design of their warning service. Everybody's scenarios included as combination of aspect-independent and aspect-dependent avalanche prone areas and one and two avalanche problems. Since the Swiss avalanche forecast format is

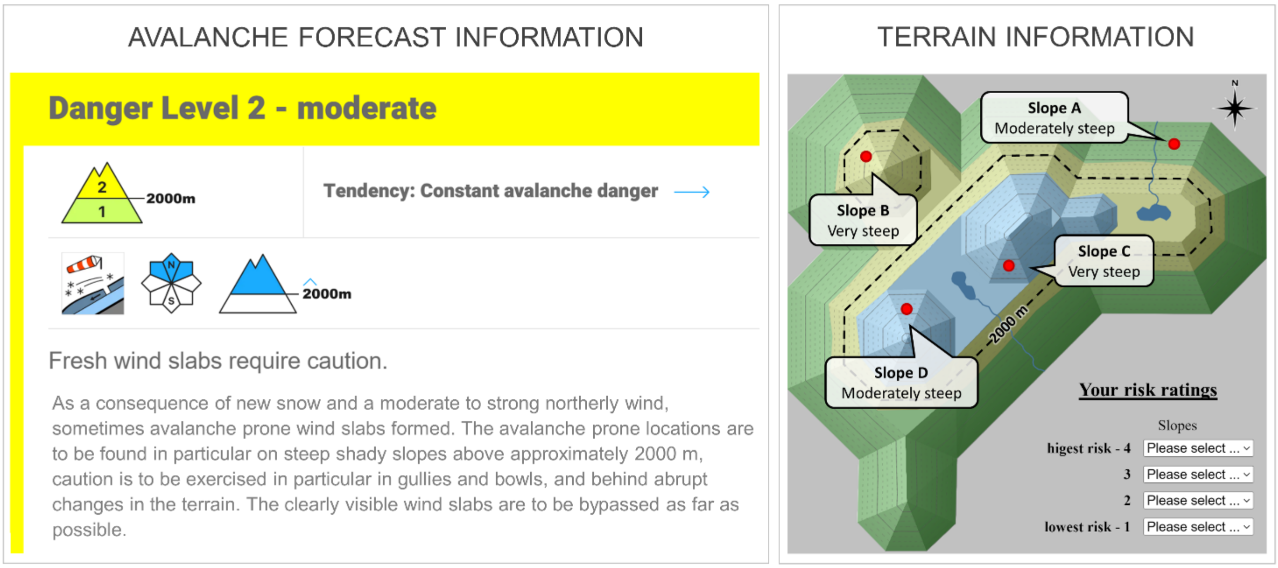

Figure 1: Presentation of avalanche forecast and terrain information in slope ranking exercise (Scenario 3 in Euregio layout).

unable to display hazard situations where the danger rating between the avalanche prone areas and the surrounding areas differs by two levels, members of the Swiss research panel only presented with Scenarios 1-4, whereas the Euregio participants saw all scenarios.

Participants' task was to study the presented information and rank the four slopes with respect to the degree of avalanche risk using the dropdowns provided (Figure 1). Completing this exercise correctly required several skills. To gather the relevant information, participants first needed to know that higher danger rating levels result in higher levels of personal risk. Second, they needed to know that the (highest) posted danger rating only applies to the aspect and elevation combination of the avalanche prone areas, and the rating in all other areas is at least one level lower unless indicated otherwise. While this is shown explicitly in the graphics of the Euregio forecasts (Figure 1), it is implied in the Swiss forecasts (WSL Institute for Snow and Avalanche Research SLF, 2022). To apply the information, participants first needed to be able to identify the highlighted aspect and elevation segments of the avalanche prone areas on the map, and second, they needed to combine the identified hazard rating with the knowledge that steeper slopes are more dangerous. While it is still possible to be exposed to avalanches on moderately steep slopes (< 30°), they are generally not considered avalanche terrain (Harvey et al., 2022).

Combining the hazard rating with slope steepness to assess personal risk can be approached in several ways. The Graphic Reduction Method (GRM) developed by Werner Munter and promoted by the *Caution Avalanches!* pamphlet of the Swiss avalanche warning service offers a graphic approach for combining the information (Figure 2). The information for each slope can be plotted on the chart, and the colored shading shows their respective risk levels. For Scenario 3 shown in Figure 1, this approach produces the rank order B > C > D > A (highest risk to lowest) (Figure 2). Alternatively, participants can use a sequential approach where they first divide the four slopes into two groups based on the danger rating and then rank the slopes within each group by steepness, or they can do it the other way around using steepness first. For Scenario 3, using the danger-rating-first-steepness-second approach results in the B > D > C > A rank order, whereas using the steepness-first-danger-rating-second approach produces the B > C > D > A rank order. Once participants had completed their two ranking tasks, they were presented with a follow up question that asked them to elaborate on how they approached the task.

Knowledge of slope steepness terms

Due to the strong influence of slope steepness on avalanche risk and the prominence of steepness terms in the description of avalanche terrain and avalanche hazard, the survey also included questions to assess participants' understanding of the qualitative terms used by the European avalanche warning services to describe slope steepness (moderately steep, steep, very steep, and extremely steep). The terms were presented to participants in random order, and participants were asked to specify the lower and upper bounds of the steepness range represented by each term using degrees (0° to 90°). Subsequently, participants were asked to rate their confidence in their answers on a scale from 0 (not at all confident) to 100 (extremely confident). In addition, they were asked to rate their confidence in their personal skills to assess slope steepness on maps without incline shading, on maps with incline shading, and in the field.

2.2 <u>Analysis approach</u>

All of the statistical analyses were performed in R statistical environment (R Core Team, 2023).

Slope ranking exercise

For the analysis of the slope exercise, the rank order patterns were tabulated for each of the six scenarios and compared to possible solutions from the GRM and sequential approaches. The scenarios were carefully designed so that participants' rank order would allow us to identify what approach was applied and what information considered (e.g., ignored aspect information). In situations where multiple approaches mapped onto the same rank order pattern, we gave participants the benefit of the doubt and assumed that they used the more complete approach. For example, it was not possible to distinguish between the GRM and the sequential steepness-first-danger-rating-second approaches in Scenarios 1-4. Hence, we assumed that all participants with the GRM rank order pattern used that approach in these four scenarios. The two approaches resulted in distinct response patterns in Scenarios 5 and 6 where the danger rating in the avalanche prone areas and surrounding areas differed by two levels, but these scenarios were only seen by Euregio participants.

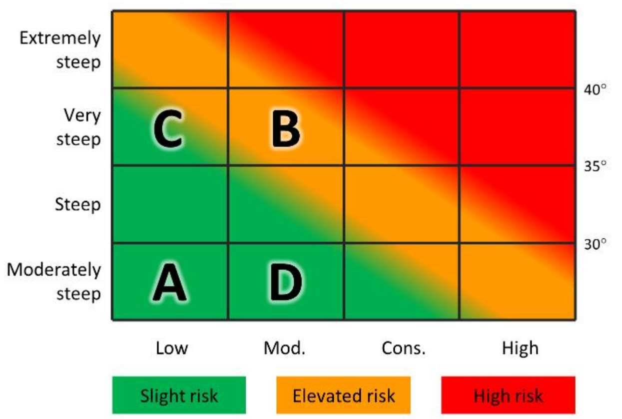

Figure 2: Slopes of Scenario 3 plotted on the Graphic Reduction Method chart.

To summarize the results, we grouped the rank order patterns into four different response classes:

1. GRM approach with all information,
2. Sequential application of all information,
3. Errors/omissions in the information gathering or application stages, and
4. Indecipherable approaches.

The proportions of the different classes were then qualitatively compared against the characteristics of the scenarios to provide initial insight about participants' information gathering and application practices.

Knowledge of slope steepness terms

Participants' responses for the lower and upper bounds of the steepness terms were compared against their definitions (European Avalanche Warning Services, n.d.) with a 2° buffer. This means that any responses between 28° and 32° were considered correct for the lower bound of steep, which is defined as ≥ 30°. To assess participants' overall grasp of the terminology, the number of errors was added for each participant. These counts were then compared with participants' confidence ratings to identify a potentially problematic group of individuals with errors but high confidence. To provide insight about who these individuals are, we performed a conditional inference tree analysis (CTree, Hothorn et al., 2006) using the ctree function of the partykit R package (Hothorn and Zeileis, 2015). This analysis linked participants' performance to various background variables, which we pulled from the signup survey of the research panels (primary backcountry activity, years of backcountry experience, days per year in avalanche terrain, forecast use frequency, level of formal avalanche safety training, age category, gender, and panel membership).

3. RESULTS

A total of 2145 backcountry recreationists completed the survey by April 30, 2022, with an almost perfectly even split between users of the Euregio and Swiss avalanche forecast products (1061 vs. 1084). Unsurprisingly, the sample was dominated by backcountry skiers (82%) and recreationists with considerable experience. Fifty-seven percent had more than 10 years of backcountry experience, 76% spend more than 10 days in the backcountry each winter, and 89% completed a formal avalanche safety course (42%: introductory; 47% advanced).

Slope ranking exercise

Of the 4290 slope assessments, 17% were consistent with the GRM approach using all the available hazard and terrain information (Table 2). However, in four of the six scenarios, this rank order pattern was also consistent with the sequential steepness-first-danger-rating-second approach. Distinguishing the two approaches was only possible in Scenarios 5 and 6, where less than 1% and 4% of the responses were consistent with this sequential approach respectively. Assuming that these observations are indicative of the general split between the two approaches, we conclude that likely only about 15% (95% confidence interval: 8-25%) of the GRM response pattern in Scenarios 1-4 came from the steepness-first-danger-rating-second approach. Hence, the steepness-first-danger-rating-second approach was not used very often.

More than half of all responses (55%) were consistent with the danger-rating-first-steepness-second approach using all information provided. Another quarter of the assessments (27%) used an identifiable assessment approach but included errors in either the information gathering or application phase. The assessment approach was indecipherable in only 2% of the responses.

Table 2: Proportions of response classes for different scenarios and overall

Response classes	Scenario with number of assessments in bracket						Overall
	1 (1073)	2 (1072)	3 (809)	4 (807)	5 (263)	6 (266)	(4290)
GRM approach with all information	23	14	13	18	8	18	17
Sequential application of all information (1. Steepness → 2. Danger rating)	n/a[a]	n/a[a]	n/a[a]	n/a[a]	<1	4	2[b]
Sequential application of all information (1. Danger rating → 2. Steepness)	69	77	41	26	30	72	55
Errors/omissions in the information gathering or application stages	7	8	46	55	57	8	27
Indecipherable response	2	1	<1	2	5	2	2

[a] Indistinguishable from GRM solution.
[b] Calculated only over the relevant dataset (Scenarios 5 and 6)

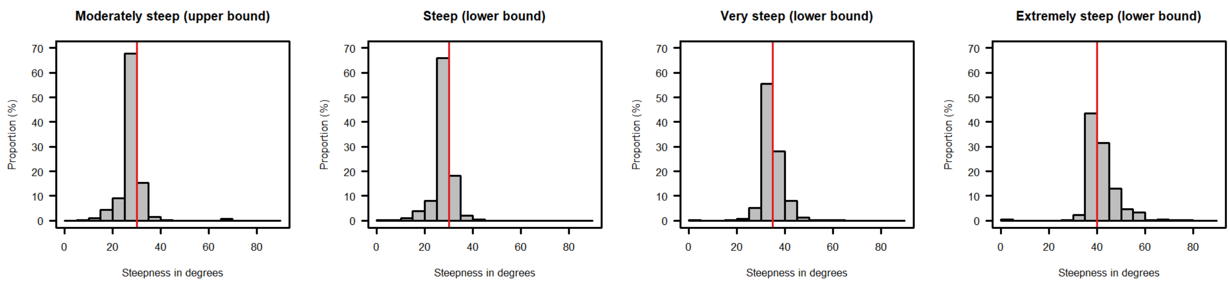

Figure 3: Distributions of responses to slope steepness questions with red vertical line indicating definition.

The proportions of the different response classes (Table 2) vary considerably among the different scenarios. Most prominently, the scenarios with aspect-dependent avalanche prone areas (Scenarios 3-6) show a much higher percentage of assessments with potential errors and omissions.

In Scenario 4 (old snow: W-N-E above 2200 m; new snow: all aspects and elevations), the most common rank order pattern (n = 268, 33% of assessments) was consistent with a sequential danger-rating-first-steepness-second approach that ignored the aspect information of the avalanche prone areas. Overall, 39% of the decipherable assessments in this scenario ignored the aspect information.

In Scenario 3 (wind slabs: NW-N-NE above 2000 m), several rank order patterns were consistent with participants using elevation differences between slopes (as seen on the map) to differentiate the risk between slopes with the same danger rating. In other words, they identified the slope at higher elevation to be riskier regardless of its steepness. Overall, such an approach was identifiable in about one third of the responses in this scenario (n = 261) including the second most prevalent rank order pattern.

In Scenario 5 (wet snow: E-S-W below 2000 m), aspect played a more dominant role and elevation was commonly ignored. A substantial proportion of participants (21%) assessed the slopes outside of the avalanche prone areas based on whether their aspect is within the E-S-W range and not steepness. Furthermore, an additional 34% of assessments only focused on the aspect information of the avalanche prone areas and ignored elevation all together.

We did not find any special rank order patterns in Scenario 6 (old snow: W-N-E above 2000 m; new snow: all aspects and elevations), where 72% of the assessments were consistent with the danger-rating-first-steepness-second approach, and another 18% with the GRM assessment.

Knowledge of slope steepness terms

Participants' responses to the slope steepness term questions revealed interesting patterns (Figure 3). Roughly two thirds of participants (68%) responded with the correct upper bound for *moderately steep* and lower bound for *steep* (both 30°). For both terms, the incorrect answers were evenly split between too low or too high. For *very steep*, the percentage of correct responses for the lower bound (35°) decreased to 59%, and 34% provided a value that was too high. The pattern continued with *extremely steep*, where only 46% of the responses were correct (40°), and 51% entered a value that is too high. Of the participants who completed all steepness questions (n = 1931), 41% answered all of them correctly, 11% had one error, 18% two errors, 10% three errors, and 21% did not provide any correct answers.

Participants' median confidence rating in their answers was 70 with an interquartile range of 52 to 80 (n = 1900). Tabulating the number of errors against ranges of confidence ratings allows us to identify a problematic group of 449 participants who are potentially overconfident in their understanding of the steepness terms (Table 3).

Table 3: Number of errors in steepness assessments versus confidence. Potentially problematic group highlighted in grey.

Num.	*Confidence ratings*				
errors	*0-20*	*21-40*	*41-60*	*61-80*	*81-100*
0	8	28	151	330	264
1	6	14	52	97	31
2	13	49	128	119	32
3	2	20	71	69	21
4	17	51	100	164	63

Our CTree analysis relating the number of errors to various background variables highlighted that formal avalanche safety training had the strongest association with performance. Within the sample that answered all background questions (n = 1553), participants with advanced recreational or professional level avalanche safety training made significantly fewer errors than participants with introductory level training or no training at all. The CTree analysis contrasting the potentially problematic group against the rest of the sample did not find any significant differences in background variables.

Participants' confidence ratings in their ability to accurately assess slope steepness was lowest for maps without incline shading (median: 52; interquartile range: 38-70) but dramatically higher for maps with incline shading (median: 86; interquartile range: 74-94; Paired t-test: $p < 0.001$). Participants' confidence in their skills to accurately assess slope steepness in the field had a median of 70 and an interquartile range of 58-80.

4. DISCUSSION

Our analysis provides several insights into participants' understanding and application of avalanche forecast information. Overall, a systematic approach with properly identified avalanche prone areas was employed in about 70% of the assessments, which is encouraging.

The GRM was only used in about one sixth of the slope ranking exercises. This is somewhat surprising given that the GRM is probably the most widely known decision aid for backcountry recreationists in Europe and features prominently in Swiss avalanche awareness materials (e.g., Harvey et al., 2022). However, we have not yet tested whether there was a significant difference in the use of the GRM approach between the Swiss residence and the residence of other countries.

In more than half of the assessments (55%), participants used the sequential danger-rating-first-steepness-second approach with all of the available information. Even though not exactly equivalent, the sequential nature of this approach has similarities with fast-and-frugal trees (Martignon et al., 2012), one of the heuristic decision approaches described in the cognitive science literature. While the use of a systematic approach that includes all information is encouraging, it is important to point out that it did not produce the most meaningful ranking. Since moderately steep slopes (<30°) are not considered avalanche terrain, splitting the slopes by steepness first and danger rating second would have been more meaningful in our scenarios. However, the prominence of this approach in our exercise could reflect the common trip planning practice of first identifying forecast areas with lower danger ratings and then choosing a trip appropriate for the conditions within these areas.

The aspect information was ignored in a substantial number of assessments in some of the scenarios where the locations of the avalanche prone areas was aspect dependent (Scenario 3: 26%; Scenario 4: 39%), which is concerning.

In other scenarios, participants included additional terrain information beyond the avalanche prone areas in their assessments. More heavily weighing elevation for wind slabs (Scenario 3) and aspect for wet snow problems (Scenario 5) is completely reasonable and might indicate higher levels of avalanche risk management knowledge. However, it still does not seem reasonable to ignore slope steepness in these assessments.

Only about half of our participants provided the correct answers to all questions about the qualitative steepness terms. Participants' knowledge was generally worse for the higher steepness classes, and their perceptions were biased towards higher steepness values. This means that they think *very steep* and *extremely steep* terrain are steeper than they actually are based on the definition. This can lead to terrain choices that are more aggressive than intended. The observed association between participants' performance on these questions and their training indicates that the qualitative steepness terms are less accessible and therefore less useful for forecast users with no or only introductory avalanche safety training. This is consistent with the findings of Fisher et al. (2022b), who highlighted the negative impact of jargon on the usefulness of travel and terrain advice statements for forecast users with no or only introductory level training. The introduction of incline shading on maps has increased participants' confidence in their ability to assess slope angles substantially, but their confidence in their in-field slope assessment skills is limited and has space for improvement.

Management implications

We draw the following management implications from our results:

- Despite participants' systematic approach to the slope ranking exercise, most of them would benefit from the use of a decision aid to ensure the forecast information is used as intended.
- Using actual degree values instead of the qualitative terms would likely make the terrain descriptions more accessible and potentially prevent unintended travel into steeper terrain.
- Participants would benefit from tools helping them assess steepness both during trip planning and in the field.

Limitations

While the present study offers interesting insights, several limitations need to be considered. Like in most online survey studies, our sample is biased towards individuals who are more committed to their backcountry activities and more avalanche aware. Hence, the highlighted challenges in forecast information understanding and use are likely more prevalent in the full forecast user population.

It is also important to remember that the slope ranking exercise only represents a very limited aspect of trip planning, and the study only used a limited number of hazard scenarios. Hence, caution is advised when extrapolating the specifics of our results and implications to trip planning in general and across a wider range of avalanche hazard scenarios. Future research could explore the possibility of using more sophisticated experimental designs that explicitly incorporate more of the relevant factors.

5. CONCLUSION

The results of this study contribute to a growing body of research that aims to provide a user perspective on the effectiveness of avalanche risk communication products by examining how backcountry recreationists understand and apply avalanche forecast information.

Using an online survey, we studied how users combine the avalanche forecast information with additional avalanche knowledge to assess the severity of the conditions on individual slopes, which is a critical skill for the effective application of the forecast information during trip planning.

Our results indicate that a substantial proportion of avalanche forecast users would likely benefit from tools assisting them with the application of the forecast information. While various analog (e.g., GRM) and digital tools (e.g., White Risk, Skitourenguru website) exist, they also need to be tested to ensure that users utilize them in the intended ways.

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