PRACTITIONERS' INTERPRETATION OF AVALANCHE PROBLEM TYPE AND DISTRIBUTION WITHIN THE CONCEPTUAL MODEL OF AVALANCHE HAZARD

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ABSTRACT: The Conceptual Model of Avalanche Hazard (CMAH) was created to be a systematic, consistent workflow for avalanche hazard and risk assessment. It is a cornerstone decision aid for information exchange between many practitioners. The US lacks a centralized organizational structure for avalanche risk management. As a result, there is a wide variety of parallel operational practices, and it is unknown how many practitioners use CMAH daily. It is also unknown how individual professionals interpret the various components of CMAH in their assessments.

We created a survey to investigate how avalanche practitioners engage with CMAH in their daily workflow. We also asked how they interpret the avalanche problem type and distribution steps of CMAH. The survey was distributed to practitioners in the US through personal and professional networks. This analysis is based on 100 survey responses.

Of our survey participants, a large majority are at least "very" familiar with CMAH and use it as part of their daily workflow. Interquartile ranges were calculated to gauge consensus amongst practitioners for how frequently an avalanche type has a given distribution. Consensus shifts appear to depend on distribution category and avalanche type. For example, there is good consensus amongst respondents that wind slabs often have a specific distribution. Meanwhile, there is poor consensus on how frequently wind slabs have a widespread distribution. Non-parametric statistical tests were used to identify significant differences between practitioners from different climates and different professions. No results reached statistical significance after correction. Several results suggest items that warrant further study such as differences between Maritime and Continental practitioners.

Effective use of structured decision-making workflows depends on consistent interpretation across user groups. Consensus regarding the frequency which practitioners believe different avalanche types have a discrete distribution varies from poor to good on an item-by-item basis. It is worthwhile to seek out ways to improve consensus. Decreasing variability in how practitioners consider avalanche problem type and distribution would improve hazard and risk assessment. We hope that our findings help spur conversations about the nuances of differing interpretations amongst practitioners.

KEYWORDS: Conceptual Model of Avalanche Hazard, Decision Aid, Avalanche Forecasting, Expert Interpretation, Avalanche Type, Distribution

1. INTRODUCTION

It is generally accepted across disciplines that structured decision aids improve judgment "accuracy by reducing inconsistency, or 'scatter; in professional forecasts." (Ashton et al. 1994). The Conceptual Model of Avalanche Hazard (CMAH) was introduced in 2010 and formally published in 2018 as a structured decision aid. It "identifies the key components of avalanche hazard and structures them into a systematic, consistent workflow for hazard and risk assessments" (Statham et al. 2018). It has become a cornerstone for generating hazard and risk assessments as well as promoting consistency in information exchange amongst avalanche professionals. The United States avalanche community lacks a centralized information exchange, such as the global InfoEx platform, and as a result there is uncertainty as to how many avalanche practitioners in the United States utilize CMAH and integrate it into their daily workflow. The European Avalanche Warning Services (EAWS) Matrix is a similar tool used to help forecasters determine avalanche danger (Müller et al. 2025). Research has been conducted using inter-rater reliability between forecasters and the impact on danger level estimations using the EAWS Matrix (Techel et al. 2024). Analogous research has not been conducted assessing how practitioners in the United States interpret the various steps of CMAH. As a result,

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there is uncertainty around potential variability in interpretations. This project aims to better understand how practitioners incorporate CMAH into their daily workflows. Analysis of survey results seek to identify potential deviations in how practitioners interpret the avalanche types and distribution steps of CMAH based on climate and profession.

2. SURVEY

The survey structure consists of three parts: background, workflow and operation, and avalanche type and distribution. The background portion defined demographic characteristics of survey respondents, including primary role in the avalanche industry, adjunctive or past roles, highest level of avalanche training, and primary snow climate the respondent is working in. The workflow and operation portion defined to what extent CMAH is incorporated into the respondents' daily workflow. The avalanche type and distribution portion assessed for the respondents' sense of how frequently any given avalanche type has a given distribution. This section included questions asking respondents to rate their confidence in identifying direct and delayed action avalanche problems. Finally, there were questions pertaining to how strongly certain terrain characteristics influenced the formation and release of various avalanche types. For the purposes of this project, we have chosen to defer addressing the findings from the terrain characteristics and confidence in locating questions, as they were not found to be contextually relevant to the stated goal.

The survey was distributed to avalanche practitioners in the United States through personal and professional networks, including the American Avalanche Association professional membership network and newsletter. This explorative analysis is based on 100 survey responses.

3. METHODS

Initial analysis of survey data focused on basic survey statistics including means, medians, and standard deviations. After a broad overview of responses, we focused our analysis on question 17 (Q17). Q17 is a 27-part matrix question asking participants to rate how frequently on a 1-5 scale a given avalanche type has an isolated, specific or widespread distribution. We calculated interquartile ranges (IQRs) and performed exploratory Kruskal-Wallis and Dunn's tests on Q17 responses. Kruskal-Wallis tests are used to determine if there are statistically significant differences between three or more groups. Dunn's test is used to determine if there are statistically significant differences between two groups.

IQRs measure the spread of the middle 50% of a data set. This can be used to gauge consensus within a group of responses. For our 1-5 scale an IQR of 0 represents good consensus between respondents while an IQR score of 2 represents poor consensus. We calculated global IQRs for all 27 matrix items. We also created algebraic graphs of response distributions to visually identify items with bimodal distribution. In this case a bimodal distribution of responses may indicate a true split in respondents' perceptions while a unimodal distribution generally indicates that responses cluster around a single peak.

Respondents were asked to identify which snow climate they typically work in. We pooled responses into the three snow climate groups to conduct an exploratory analysis of Q17. We ran a Kruskal-Wallis test for all 27 items. We then ran a Holm correction to control for false positives. After our Kruskal-Wallis test we ran an exploratory Dunn's test. With 27 items and 3 pairwise groups we ran 81 tests. We then applied a Holm correction to these results to check for false positives. Finally, IQRs were calculated for all three climate groups and average IQRs were calculated for each group.

Respondents were asked to indicate their primary profession in the avalanche industry. To improve statistical power, respondents were pooled into four groups: 28 public backcountry forecasters, Group 1; 31 ski patrollers, ski area forecasters, and technicians, Group 2; 26 ski and mountain guides, mechanized guides, and avalanche educators, Group 3; and 12 transportation and industrial forecasters, Group 4. Two responses were excluded because no profession was chosen and one respondent who indicated Pro SAR was also excluded. Using these profession pools we performed a Kruskal-Wallis test with Holm correction. We also ran an exploratory Dunn's test with Holm correction. With 27 items and 6 pairwise groups this makes for 162 tests. Finally, we calculated IQRs for all four professional groups and average IQRs were calculated for each group.

4. RESULTS

4.1 Overview

A total of 100 practitioners participated in the survey. All participants did not complete the entire survey, leading to variable response rates from question to question. The most common single profession was public backcountry forecasters, 28 of 98. Only one individual reported that their primary profession was Pro SAR. Many avalanche practitioners have secondary professions in the industry, with only 24 participants reporting that they don't, and 10 do not answer the question. This suggests that approximately 65% of

participants currently have more than one profession. The most common secondary profession was avalanche education 30, followed by ski or mountain guiding 15, professional ski patrolling 8, and mechanized guiding 8. Respondents to our survey had a high level of experience ranging from 2-50 seasons. The median level of experience was 14 seasons. 89% of respondents report being either “very” or “extremely” familiar with the CMAH while 75.5% of respondents report using the CMAH as part of their daily routine.

4.2 Global Analysis

Global IQRs calculated for Q17 generally showed moderate consensus, with 16 out of 27 items resulting with IQR=1.0. Other items showed good or poor consensus. For example, there is good consensus among respondents for how frequently wind slabs have specific distribution, IQR=0.0. Meanwhile, there is poor consensus pertaining to how frequently wind slabs have a widespread distribution, IQR=2.0 (Fig. 1). Of all the avalanche type and distribution parings with moderate to poor consensus, glide-isolated, IQR=1.0, was the only combination with a true bimodal distribution. One cluster of responses denoted “never”, and a larger cluster of responses denoted “often” (Fig. 2). Other items with IQRs between 1.0-2.0 have a generally wide distribution of responses with a single peak.

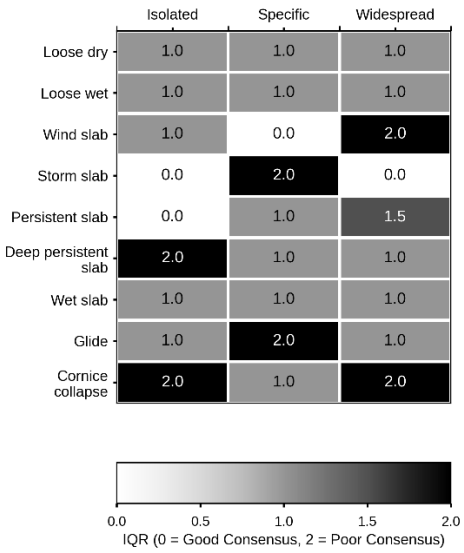


Figure 1: Interquartile range (IQR) of respondent ratings (1 = Never – 5 = Always) for each avalanche problem type and distribution.

4.3 Responses Pooled by Climate

Of 97 respondents, 42 reported working in a Maritime climate, 37 in an Intermountain climate, and 18 in a Continental climate.

The Kruskal-Wallis test flagged six items with a significant p(raw)≤0.05. A holm correction was applied across all 27 tests and no results reached significance after correction (Tabel 1).

Of the 81 pairwise comparisons in Dunn’s test, no comparison reached significance after correction. The smallest corrected p-value was 0.113 for persistent slab-specific, Maritime vs. Continental (Tabel 2).

Average IQRs were nearly identical across climate groups: Maritime: 1.00, Intermountain: 1.06, and Continental: 1.10. IQRs appear to be driven

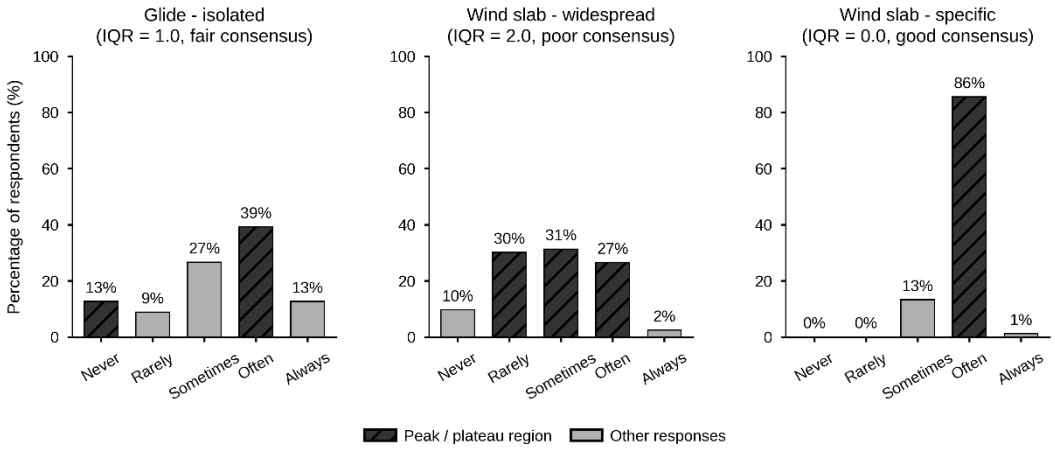


Figure 2: Range of response patterns in Q17: bimodal fair consensus, flat/plateaued poor consensus, and good consensus.

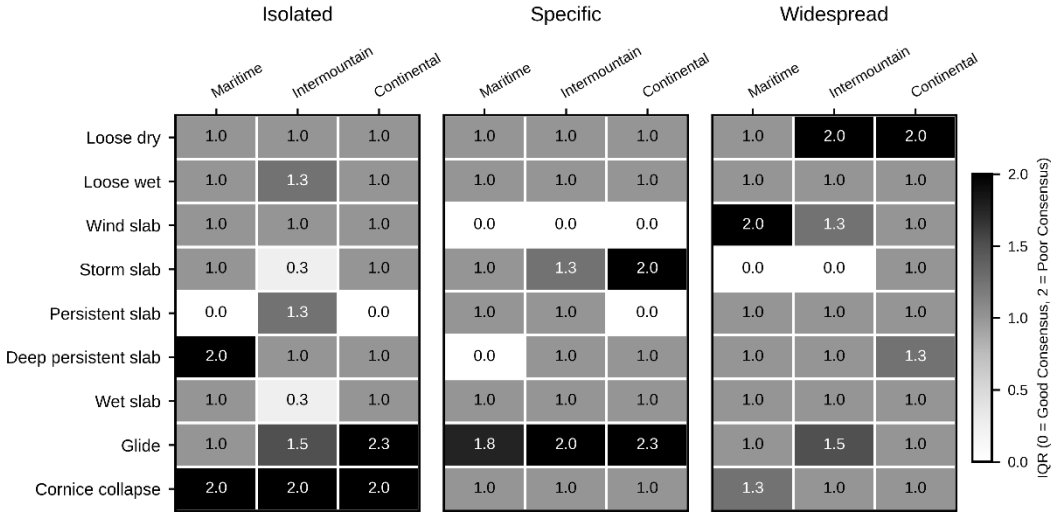


Figure 3: Interquartile range (IQR) of respondent ratings (1=Never, 5=Always) for each avalanche problem type, by distribution and snow climate group.

by specific avalanche type and distribution combinations rather than by climate group. For example, wind slab-specific has good consensus, IQR=0.0, in all three climates, while cornice-isolated shows poor consensus, IQR=2.0 across all climates (Fig. 3).

Tabel 1: Kruskal-Wallis Test Results for Q17 Items with p(raw)≤0.05

Item	p (raw)	p (Holm)
Persistent slab-specific	.0046	.125
Loose dry-widespread	.0166	.432
Loose wet-widespread	.0325	.814
Wind slab- specific	.0437	1.000
Persistent slab- widespread	.0450	1.000
Loose wet- isolated	.0480	1.000

Tabel 2: Exploratory Dunn's Test Results for Q17 Pairwise Comparisons with p(raw)≤0.05

Item	Comparison	p (raw)	p (Holm)
Persistent slab-specific	Maritime vs. Continental	.0014	.113
Loose wet-widespread	Maritime vs Continental	.0089	.712
Loose dry-widespread	Maritime vs. Continental	.0093	.732
Loose wet- isolated	Maritime vs. Intermountain	.0193	1.000
Persistent slab-widespread	Maritime vs. Continental	.0204	1.000
Storm slab- isolated	Maritime vs. Continental	.0217	1.000
Wind slab- specific	Maritime vs. Intermountain	.0305	1.000
Loose dry-widespread	Maritime vs. Intermountain	.0431	1.000
Loose wet-Widespread	Intermountain vs. Continental	.0499	1.000

4.4 Responses Pooled by Profession

97 respondents were pooled into four groups based on their primary profession. 28 public backcountry forecasters make up Group 1. 31 ski patrollers, ski area forecasters, and avalanche technicians make up Group 2. 26 avalanche educators along with ski, mountain, and mechanized guides make up Group 3. Finally, 12 transportation and industrial forecasters make up Group 4.

The Kruskal-Wallis test returned no significant results after correction. The test flagged isolated wet slabs as the only item with significance before correction, p(raw)≤0.05 (Tabel 3).

None of the 162 pairwise Dunn's tests reached significance after correction. The smallest uncorrected p-value was for wet slab-isolated, Group 1, public backcountry forecasters vs. Group 3, ski, mountain, mechanized guides, and avalanche educators, p(raw)=0.0082. Four out of the five items with a p(raw)≤0.05 were between Group 1 and Group 3 (Tabel 4).

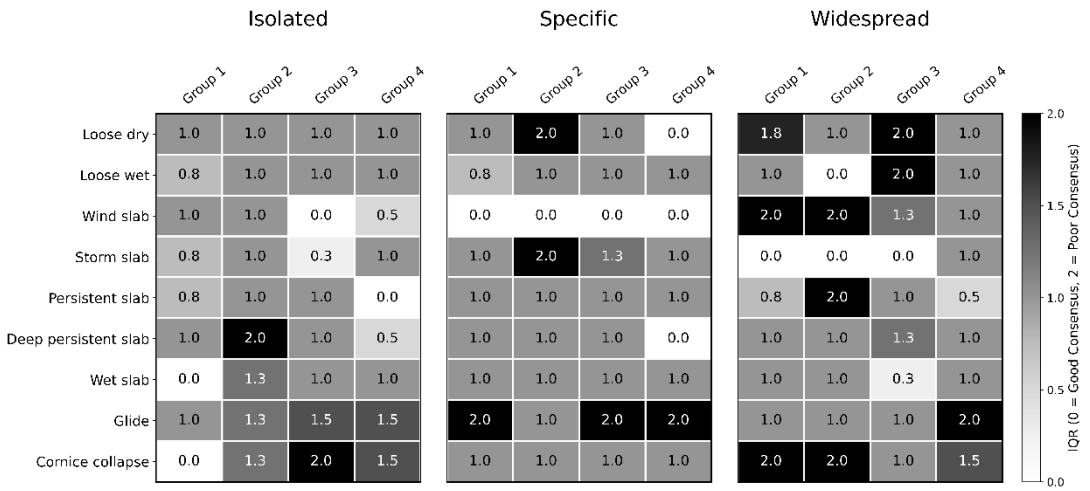


Figure 4: Interquartile range (IQR) of respondent ratings (1 = Never, 5 = Always) for each avalanche problem type, by distribution and profession group. Group 1: public backcountry forecasters. Group 2: ski patrollers, ski area avalanche technicians & forecasters. Group 3: ski, mountain, & mechanized guides, & avalanche educators. Group 4: highway & transportation forecasters.

Average IQRs across all four professional groups show moderate to good within group consensus: Group 1: 0.94, Group 2: 1.14, Group 3: 1.03, and Group 4: 0.93. As with climate-based grouping, IQRs appear to be driven by specific avalanche type and distribution combinations (Fig. 4).

Tabel 3: Kruskal-Wallis Test Results for Q17 Items with p(raw)≤0.05

Item	p (raw)	p (Holm)
Wet slab- isolated	.0503	1.000

Tabel 4: Exploratory Dunn's Test Results for Q17 Pairwise Comparisons with p(raw)≤0.05

Item	Pair	p (raw)	p (Holm)
Wet slab- isolated	Group 1 vs. Group 3	.0082	1.000
Glide- isolated	Group 3 vs. Group 4	.0118	1.000
Deep persistent slab- isolated	Group 1 vs. Group 3	.0120	1.000
Glide- isolated	Group 1 vs. Group 3	.0360	1.000
Loose wet- isolated	Group 1 vs. Group 3	.0376	1.000

5. DISCUSSION

Since the introduction of the CMAH, little research has been done to evaluate how practitioners integrate the tool into their daily workflow. We found that most practitioners who participated in the survey are familiar with CMAH and integrate it regularly. This demonstrates broad acceptance of CMAH amongst avalanche practitioners in the United States despite the lack of a centralized organizational structure for avalanche risk management.

Our survey sought insight into how practitioners interpret the distribution component of CMAH. We specifically asked how frequently practitioners perceive a given avalanche type as isolated, specific, or widespread in its distribution. Our exploratory interquartile analysis indicates moderate consensus for most avalanche type and distribution combinations. It appears that respondents have a mix of good to poor consensus for both direct action and delayed action avalanches. Consensus shifts depend on distribution category and avalanche type. Most items with good consensus have clear, well-understood formative mechanisms such as widespread storm slabs and specific wind slabs. It is curious that other distributions of these same, well-understood avalanche types showed comparatively poor consensus. For example, perceived frequency of both widespread wind slabs and specific storm slabs showed poor consensus. Of all items with moderate or poor consensus only glide-isolated had true bimodal distribution while all other items had a single peak. Taken together, these results could reflect differing interpretations of the ordinal frequency scale, or genuine disagreement among practitioners about how frequently these avalanche types can be distributed across terrain.

Prior to analysis we hypothesized that there may be significant differences between professions with a "mitigation" focus and those without. Tests used to identify differences between professional groups produced no statistically significant results after Holm correction. When running a high

number of Dunn's pairwise tests false positives, p(raw)≤0.05, are expected to occur. Four out of the five items with a p(raw)≤0.05 were between the public forecaster group and the guide/educator group. This suggestive result differed from our expectation that differences between mitigation-focused and non-mitigation focused roles would come closest to significance. These results are only suggestive. Differences between practitioners may arise from aspects outside of a simple mitigator vs. non-mitigator framing and could be considered for future research.

We hypothesized that climate would influence practitioners' perceptions of how frequently different avalanche types have a given distribution. Non-parametric tests used to identify differences failed to meet statistical significance after Holm correction. The exploratory Dunn's test did produce nine items with a p(raw)≤0.05. Most items with a p(raw)≤0.05 were between Maritime and Continental respondents. Only one of the nine items flagged did not involve respondents from a Maritime climate. Most of the items flagged involved direct action avalanche types. But the item with the lowest corrected p value was for persistent slabs' specific distribution between Maritime and Continental respondents. It is tempting to accept this suggestive result as intuitive because the development of persistent weak layers is a defining characteristic of thin and cold Continental snowpacks. However, persistent weak layers do form in Maritime snowpacks and can be present in fatal avalanche accidents. The February 28, 2025, accident on Harts Pass in Washington state is an unfortunate example of this (Hirshberg & Warren, 2025). Because climate and weather are the primary drivers for snowpack formation, it is plausible that practitioners develop differing perceptions about persistent weak layers' distribution frequency. Direct action avalanche types are also driven by climate and weather and represent most of the flagged items. Our results fail to verify this hypothesis, but they do suggest that further discussion and study may be valuable.

5.1 Limitations

Statistical power was limited by modest sample size, unequal representation between climate and professional groups, and item level nonresponse. A specific example of this is the relatively small number of respondents from a Continental snow climate, N=18. Consequently, nonsignificant findings indicate a lack of detected differences and do not prove consensus among practitioners.

To maintain a manageable scope, the study examined a subset of survey questions relevant to perceptions regarding avalanche type and distribution frequency. Survey questions excluded include questions to gauge respondents' confidence in identifying different avalanche types in the field, how they rank different terrain characteristics' effect on the formation of avalanches, how often they use different avalanche types, and what avalanche types they refrain from using and why. As a result, the findings do not represent the survey in its entirety.

Broad professional groupings may obscure variation in respondents' experience, roles, terrain, and operational settings. Possible differences between professional groups are further confounded by the fact that most respondents indicated past and present work in additional professional roles.

Snow climate classifications offer a model that simplifies a continuum between geographic regions. The model does not perfectly capture transitional regions and seasonal variability. Findings based on climate are further confounded by the fact that most respondents indicated previous experience in one or more additional snow climates. Taken together with the fact that practitioners come from a wide variety of professional contexts, we cannot attribute differences to climate alone.

The use of an ordinal scale in the survey produced many tied responses. This is why we chose rank-based tests instead of evaluating medians alone. Holm corrections were applied to each pairwise test as a conservative choice to prevent false positive results. A consequence of this choice is a reduced sensitivity to modest differences.

Finally, our study utilized self-reported judgements as opposed to observing forecasting behavior. As such, any findings cannot establish causation. Results are also susceptible to self-selection bias as participation in the survey was voluntary and the pool of respondents cannot be assumed to represent all avalanche practitioners.

6. CONCLUSION

This study represents an early attempt to evaluate how practitioners interpret parts of CMAH. Due to limitations, we were unable to identify either profession or climate as definitive drivers in how practitioners interpret the distribution portion of CMAH. However, exploratory findings indicate that further research into differing perspectives between climate regions is a worthwhile pursuit.

Our analysis was limited to a small portion of the overall survey. Comments from respondents indicate that several of these excluded topics offer interesting routes for study on their own. Focused survey construction and improved distribution

would serve to expand our understanding of how practitioners perceive avalanche formation, distribution, and frequency. Including how they interpret and use CMAH. Improved understanding of how practitioners interpret and implement decision aids such as CMAH has the potential to improve forecast quality and outcomes.

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