COMPARING AVALANCHE DECISION FRAMEWORKS USING ACCIDENT DATA FROM THE UNITED STATES

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ABSTRACT: In recent years, a number of decision-making frameworks have been developed to help European recreationists make better decisions in avalanche terrain. This study evaluated how well these frameworks might perform in North America by comparing four of them (the Reduction Method, NivoTest, Stop-or-Go, and the SnowCard) and one very simple decision strategy (based on obvious clues) against 33 years of avalanche accident data from the United States.

We evaluated decision frameworks across three attributes that affect their usefulness: 1) the number of accidents prevented by each method, 2) the range of terrain available under each method (mobility), and 3) ease of use. Using binomial comparisons, we found that the preventive validity of these frameworks was statistically invariant to the level of training of the accident party, their recreation activity, and the type of slab released by the accident. In contrast, we found a generally significant sensitivity to avalanche climate, with most frameworks being significantly more conservative in maritime climates. And we found that most of these frameworks perform poorly at low and moderate avalanche hazard, which accounts for about 20% of all accidents. By computing a utility function that incorporated preventive validity, mobility and ease of use, we found that the decision method based on obvious clues was optimal in the largest number of cases. Even when combined with the risk reduction provided by mitigation measures such as wearing avalanche transceivers and exposing one person at a time to the hazard, simpler methods appear to be superior to more complex decision methods.

Keywords: decision making, avalanche education, avalanche accidents, avalanche risk

1. INTRODUCTION

In 1997, Werner Munter, a Swiss mountain guide, presented the Reduction Method (RM) as a new decision support scheme for winter recreationists who travel in avalanche terrain.

Several big avalanche accidents in Switzerland in the late 1980s prompted him to rethink the traditional snow science-oriented approach to avalanche safety, which was difficult for recreationists to learn and use. His goal was to reduce avalanche fatalities in Switzerland by 50% by providing clear and easy to understand rules for making decisions in avalanche terrain.

Soon after the introduction of the RM, other decision support frameworks followed. Larcher (1999) presented the Stop-or-Go method (SoG); Engler and Mersch (2000) developed the SnowCard (SC) and Bolognesi (2000) introduced the NivoTest (NT).

While the methods were generally well received by recreationists, their introduction created controversy about decision-making and avalanche education in the professional avalanche community in Europe. Due to the lack of related literature in English, the methods have so far not been widely used in North America. However, the major avalanche winter of 2002/03 in Western Canada highlighted the need for similar decision frameworks in North America.

The purpose of this study was to evaluate the applicability of avalanche decision frameworks in the United States and other areas having similar

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avalanche accident characteristics. In this study, we evaluated overall framework utility as a combination of three attributes: 1) *preventive validity*, or the degree to which each framework would prevent accidents, 2) *mobility*, or the range of terrain accessible under each framework, and 3) *ease of use*. We also evaluated the benefits of two common hazard mitigation measures: carrying an avalanche beacon and exposing only one person at a time to the hazard.

2. DESCRIPTION

This section briefly describes each decision support framework. Due to space limitations, we provide very superficial descriptions here; a more detailed discussion appears in McCammon and Hägeli (2004).

2.1 Reduction Method (Munter, 2003)

The Reduction Method was intended as an instrument for verifying decisions made using a traditional, knowledge-based approach. The method is based on a risk equation that balances environmental conditions against a number of standard safety measures

$$\textit{residual risk} = \frac{\textit{danger potential}}{\prod(\textit{reduction factors})} \leq 1.0 \qquad (1)$$

The danger potential represents the existing snowpack conditions and is directly derived from the avalanche hazard rating of a public advisory. Its value doubles from one rating to the next (low: 2; moderate: 4; considerable: 8; high: 16). By applying various safety measures (multiplying reduction factors), users can decrease the residual risk to the threshold level of 1.0. For example, traveling on slopes less than 40° (a reduction factor of 2) reduces the risk of an avalanche incident by half. Additional rules specify how and under what conditions different reduction factors can be combined.

Reduction factor values are based on statistical analyses of Swiss avalanche fatality and incident data. Values were chosen so as to reduce the avalanche risk for a "go" decision to a level equivalent to the risk of hiking or driving a car in Switzerland. The lack of terrain usage data, however, has so far prevented a complete risk analysis of the method.

In order to make the method more attractive to beginners, Munter introduced several simplifications. The Basic Reduction Method (BRM) provides four simple terrain guidelines for novices: 1) under moderate hazard rating no travel on slopes steeper than 39°, 2) under considerable hazard stay below 35°, 3) under high hazard stay below 30°, and 4) no travel during extreme hazard conditions.

2.2 Stop-or-Go (Larcher 1999)

The Stop-or-Go method uses the Basic Reduction Method as a first check of a two-step decision scheme. In the second step, the user checks for five contributing factors to avalanche danger: new snow, drifted snow, recent avalanche activity, liquid water content and whumphing. If the user determines that one of these factors poses a threat, trip plans must be altered or the trip must be rescheduled.

Larcher added this second step because he felt that the lack of traditional snow science information was a significant drawback of the Reduction Method. He acknowledges, however, that the second step of the method requires considerable experience and practice.

2.3 SnowCard (Engler and Mersch, 2000)

The SnowCard presents avalanche risk using multicolored curves on a hologram-type card. The curves show the risk level as a function of the hazard rating and slope steepness for favorable and unfavorable slopes. Generally safe slope angles & aspects are depicted in green; extra caution is advised on yellow slopes; and red slopes are not recommended for travel. The transitions between the different colors are indistinct to reflect the uncertainty inherent in this type of decision-making.

The boundaries between the different colors are mainly based on the personal experience of the developers and a limited statistical analysis of avalanche incidents. Engler (2001) verified the exponential growth of the danger potential shown on the card and the generally high reliability of information given in avalanche advisories. The graphs were also calibrated against other decision frameworks such as the BRM.

A crucial aspect of the SnowCard is its design as a teaching tool. Depending on the experience of the user and/or information available, the SnowCard can be used at different levels of expertise. Novices generally have to assume the worst possible case and only use the graph for unfavorable slopes. Highly experienced users can locally verify the avalanche bulletin information using the 'Faktorencheck'. This generally allows advanced users to access more terrain, and is intended to encourage recreationists to learn more about avalanche safety.

2.4 NivoTest (Bolognesi, 2000)

While the three previous methods use the hazard rating of the public advisory as an input parameter, the NivoTest is a tool that locally re-evaluates the hazard rating and assesses the specific avalanche risk of a particular route. The NivoTest consists of 25 yes/no questions regarding weather, snowpack conditions, recent avalanche activity, intended route and participants. Each yes answer has a numerical weight that represents the severity of the respective contributing factor. These weights were initially based on a statistical analysis of approximately 7000 avalanche and non-avalanche events. The tool was then given to professionals for further refinement.

When using the method, users answers each of the 25 questions, adding up the weights of each yes answer by turning a rotary dial on the card. Once all questions are answered, the overall assessment is given on the back of the card. A ☺ (NT score • 8) indicates generally safe conditions. A ☹ (NT score > 23) indicates unstable conditions where backcountry travel is not advised. Under suspect conditions (😐, scores between 8 and 23) backcountry travelers are advised to use extra caution. Additional standard safety measures are also described on the card.

2.4 Obvious Clues

A final method included in this study is based on the observation that most avalanche accidents happen when the danger is fairly obvious, even to people with minimal avalanche training. In this method, a user simply adds up the number of obvious clues that apply to the slope in question (Table 1). In this method, some (rather minimal) judgment is required on the part of the user to recognize avalanche paths and terrain traps. Discussions of the origins of this method can be found in McCammon (2000, 2004), and Atkins and McCammon (2004).

3. PREVENTIVE VALIDITY

To be effective in reducing recreational avalanche accidents, a decision framework must consistently identify dangerous avalanche slopes. In this study, we evaluated how well different frameworks would have identified conditions in past accidents, and the proportion of accidents that would have been prevented.

Clue	*Description*
Avalanches	In the area in the last 48 hrs.
Loading	By snow, wind or rain in the last 48 hrs.
Path	Identifiable by a novice.
Terrain trap	Gullies, trees, cliffs or other features that increase severity of being caught.
Rating	Considerable or higher hazard on the current avalanche bulletin.
Unstable snow	Collapsing, cracking, hollow snow or other clear evidence of instability.
Thaw instability	Recent warming of the snow surface due to sun, rain, or warm air.

Table 1. An example of a simple decision framework based on obvious clues. Users simply add up the number of clues that apply to the slope. The acronym ALP TRUTh is handy memory aid.

Because this analysis relies on accident data rather than usage data, it doesn’t provide insight into how well these frameworks predict accidents. The analysis does, however, reveal differences in how the frameworks might prevent accidents. Until usage data is known, the exact relationship between prevention and prediction will remain obscure.

3.1 Methods

We evaluated the preventive validity of each framework using accident data from avalanches that were unintentionally triggered by recreationists. We considered only accidents where there was sufficient information to compute an exact score for each framework. Note that because the “Check 1” component of the SoG is identical to the BRM, the results are equivalent for the two frameworks.

Because the proportion of accidents prevented by each method may not be the same under all conditions and for all users, we also examined the preventive validity of each framework across the following categories:

Level of avalanche training of the accident party, following the categorization of McCammon (2004): 1) completely unaware of the hazard, 2) aware of the hazard but lacking formal training, 3) basic formal training (the equivalent of a 2–3 day recreational avalanche course, and 4) advanced training (multiple courses taken or professional-level avalanche training).

Activity of the party at the time of the accident. The categories evaluated (skiing, snowboarding, snowmobiling and climbing) accounted for 92.3% of the accidents studied.

Avalanche climate where the accident occurred, following the definitions of Mock and Birkeland (1999) and Tremper (2001:30–33).

Slab type of the avalanche, as identified by witnesses or investigators. Hard slabs (HS), soft slabs (SS) and wet slabs (WS) accounted for 90.3% of accidents where slab type was known.

Hazard level at the time of the accident, as defined by the North American conventions for Low through Extreme avalanche hazard. Prior to about 1996, the rating “considerable” was not generally used by forecast centers in the United States, although the rating “moderate to high” sometimes appeared in bulletins.

To assess differences between proportions across categories, we used Pearson’s chi-square (2 x n contingency) test. For proportions that were significantly different (i.e. $p < 0.05$), we used the Levy Multiple comparison test to determine which categories had differing proportions. Data from categories that were not significantly different (i.e. p • 0.05) was pooled to compute the binomial 95% confidence limits for the finite population of accidents where the proportion applied.

Because these decision frameworks were designed to be used with mitigation measures such as safe travel and rescue equipment, we also evaluated their preventive validity when used in conjunction with beacons and exposing one person at a time to the hazard. We computed the proportion of accidents prevented by any (k) framework as

$$P_k = \frac{n_{f,k} + n_m}{N} = P_{f,k} + (1 - P_{f,k}) \times \prod_i P_{m,i} \qquad (2)$$

where $n_{f,k}$ was the number of accidents prevented by the framework, n_m was the number of accidents prevented by all mitigation measures, and N was the total number of accidents in the dataset (751). In the right-hand equation, $P_{f,k}$ is the proportion of accidents prevented by the framework, and P_m is the proportion of accidents prevented by the mitigation measures, multiplied over all of the measures that apply. Where they were determined to be significantly different by the Pearson chi-square test, the variables $P_{m,i}$ were computed as binomial proportions for the finite population of accidents using the Newcombe-Wilson method.

The data for this investigation came primarily from a database constructed for previous studies (McCammon, 2004) and augmented for this analysis. The data covers the period 1972–2004, for avalanche accidents in the United States including Alaska. There were a total of 751 incidents reviewed, involving 1408 people caught and 518 people killed. Accident data was used as reported, with no attempt made to fill in missing information with likely data.

3.2 Results

Accident records provided enough information to compare preventive validity across almost all categories. Table 2 summarizes the results.

We were able to compute an exact NivoTest score for 115 accidents. The upper threshold for a go/no-go decision, or a score of 23, included 65±8% of accidents. In other words, had victims followed the NivoTest guidelines, 65±8% of the 115 accidents would have been prevented. The minimum NT score was 14, somewhat higher than the lower limit for Europe of 8. The NT showed no significant sensitivity to the level of training of the victims, their activity or the slab type, although the small sample size for wet slabs precluded a meaningful comparison. The method showed significant sensitivity to avalanche climate, where preventive validities ranged from 54±13% for intermountain ranges to 79±16% for maritime ranges. The method would have prevented no accidents at low hazard levels, and a generally increasing proportion as the hazard level increased.

The preventive validity of the Basic Reduction Method could be evaluated in 280 cases. In general, the method would prevent about 80±4% of the accidents reviewed, a finding that is consistent with Munter’s (2003) projection of a 4/5 reduction in fatal accidents in the Swiss Alps. The BRM showed no sensitivity to victim training, activity or the type of slab. Like the NivoTest, the method showed significant variation in prevention levels between avalanche climates, ranging from 72±8% for intermountain ranges to 89±8% for maritime ranges. The method would have prevented no accidents at low hazard, and an increasing proportion of accidents at higher hazard levels. Recall that neither version of the Reduction Method applies when the avalanche hazard is rated extreme.

We evaluated three different residual risk values for the full Reduction Method across 229 accidents. At a conservative residual risk value of 0.5, the RM would have prevented 82±4% of the accidents, whereas a less conservative threshold of 2.0 would have prevented only 36±6% of accidents. The recommended threshold value of 1.0 would have prevented 60±5% of accidents, a finding which differs from Munter's estimate of 75% for the Swiss Alps (Munter, 2003). The RM showed no sensitivity to the level of avalanche training of the victims, their activity or the type of slab involved. At each threshold value, the method showed no distinction between the proportion of accidents prevented in intermountain and continental climates (hence their data was pooled at each threshold level), but was distinctly more conservative in maritime climates. As with the other methods, the proportion of accidents prevented rose with the hazard level.

The SnowCard was evaluated for 257 accidents at two threshold levels: the less conservative orange-red threshold (i.e. all slope angles up to the boundary between orange and red on the SnowCard) and the more conservative yellow-orange threshold (slopes angles up to the yellow-orange boundary). The overall proportion of accidents prevented ranged from 75±4% (orange) to 86±4% (yellow). The method was statistically insensitive to victim training, activity and slab type, and showed only marginal sensitivity (0.5 • *P* < 0.1) to avalanche climate. As in the other methods, preventive validity generally increased with increasing avalanche hazard.

The method based on Obvious Clues was evaluated for 252 accidents. Proportions of accidents prevented ranged from 92±3% for a 3-clue threshold to 77±4% for a 4-clue threshold. Because the preventive validity of this method drops dramatically above 4 clues, thresholds of 5 clues or greater were not evaluated. There was no significant difference in proportions of accidents prevented across training, activity and slab type, and only at a threshold of 4 clues was there a significant difference with respect to avalanche climate. As in the other methods, preventive validity generally increased with increasing avalanche hazard.

With respect to mitigation measures, there were 159 people who were critically buried with avalanche beacons. Eighty-nine of these people died. In contrast, there were 459 people that were critically buried who were known not to be wearing beacons; 313 of whom died. Thus wearing a beacon improved the survival chances of fully buried victims by about 14.1%, a mortality reduction of 7.2±4.4% across all fully buried victims. These results fall between the 19% increase in survival rate due to beacons among Canadian avalanche victims reported by Jamieson (1994), and a negligible risk reduction rate reported by Brugger and Falk (2004). Long search times for the analog beacons in this data set and variations in reporting are possible explanations for these discrepancies (Tschiriky and others, 2000).

There were 351 incidents where more than one member of a party was caught in an avalanche, resulting in 312 fatalities. Had these groups exposed only one person at a time to the hazard and had that one person sustained the maximum injury experienced by that party, 195 of these victims would have lived. Across all 751 incidents, the mortality reduction due to exposing one person at a time was 9.7±2.8%.

Figure 1 summarizes the cumulative preventive validity of mitigation measures used in conjunction with the decision frameworks. Note that in some frameworks such as the NT and RM, mitigation measures are integrated into the scoring process and thus do not add to the framework-only prevention values listed in Table 1.

3.3 Discussion

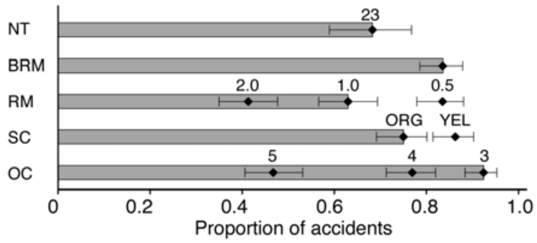

Figure 1. Proportion of accidents prevented by each framework if victims had worn beacons and exposed one person at a time. Customary thresholds are shown by the shaded bar; other thresholds shown for comparison. Error bars indicate the 95% binomial confidence limit around the data proportion ( ) for each threshold value.

All of the frameworks in this study would have prevented a substantial number of accidents, particularly at the thresholds recommended by their designers. Even the non-customary, less conservative thresholds demonstrated significant accident reduction.

Training – Preventive validity did not vary significantly with the training level of the accident party. This result indicates that conditions that kill avalanche novices are very similar to the conditions that kill more highly trained individuals, a finding that replicates other results McCammon (2004). While this result suggests that decision frameworks have the potential to significantly reduce the number of accidents, it also underscores the importance of ensuring that such systems are easy to use and permit a degree of mobility that makes them attractive to more experienced users.

Activity - The preventive validity of the frameworks was not significantly affected by activity type. Thus, concerns that these frameworks might perform differently for different users appear to be unfounded in the U.S. and similar areas.

Climate - Avalanche climate had a significant impact on the preventive validity of almost all the methods evaluated. In general, the methods performed more conservatively (i.e. potentially prevented more accidents) in maritime climates than in intermountain or continental climates. For some frameworks these differences were substantial. Thus it seems that along with instruction on how to use the frameworks, recreationists should also receive information on how preventive validity might vary by climate. Only the SnowCard and the Obvious Clues method (threshold 3) showed no significant sensitivity to avalanche climate at the 95% level.

Slab type - The frameworks appear to work equally well for hard and soft slab avalanches. Since these two slab types account for most (84.2%) accidents, this argues for the robustness of the frameworks across variable snow conditions. Wet slab avalanches, which accounted for less than 6% of all accidents, were not well evaluated in this respect due to small sample sizes.

Hazard – With the exception of the Obvious Clues method, none of the frameworks was effective at preventing accidents when the avalanche hazard was low. At moderate hazard, prevention results were mixed. The best preventive performance occurred for considerable and high hazard levels. Only two of the methods (NivoTest and Obvious Clues) can be used when the avalanche hazard is extreme.

4. MOBILITY

Decision frameworks can reduce avalanche accidents by helping users identify and avoid potentially dangerous slopes. But for many recreationists, decision making in avalanche terrain is also about maximizing opportunities to ski or ride steep and avalanche-prone slopes. Decision frameworks that too often turn people away from slopes that are subsequently tracked by others will be viewed as overly conservative, and perhaps discarded. Mobility, or the range of terrain accessible under each framework threshold, is thus of critical importance to the overall utility of these methods.

4.1 Methods

One measure of relative mobility relates to the maximum slope angle permitted under a framework threshold. Thresholds that allow access to steeper slopes permit more terrain to be available to users, and will be more attractive to recreationists seeking out challenging experiences.

Because the spatial relationship between the trigger point and starting zone generally changes with hazard level, we compared slope angle maximums only within each level of hazard. And because most frameworks do not perform well at low hazard levels or apply at extreme hazard, we considered only those accidents that occurred during periods of moderate, considerable and high avalanche hazard (about 94.5% of accidents). For numerical simplicity, we also restricted our analysis to avalanches that released on slopes of less than 50°, a constraint that includes 96.4% of accidents where the angle of the start zone was known via direct measurement.

To approximate the amount of terrain available to recreationists under each method, we computed slope-angle mobility (M_s) as the area under the slope-hazard curve (Figure 2) as a proportion of the area under the 50° curve

$$M_{Sk} = \left(\frac{A_{1k} + A_{2k}}{2A_{50}}\right) \times 10 = \frac{b_k + c_k + 0.5(a_k - c_k)}{10} \qquad (3)$$

where a, b and c are the maximum effective slope angles at each hazard level for the k^{th} framework threshold. The result is scaled to a maximum value of 10 for comparison purposes as explained in Section 5.

In the Basic Reduction Method (M,C,H hazard levels) and the Reduction Method and SnowCard (C and H hazard), the maximum slope an-

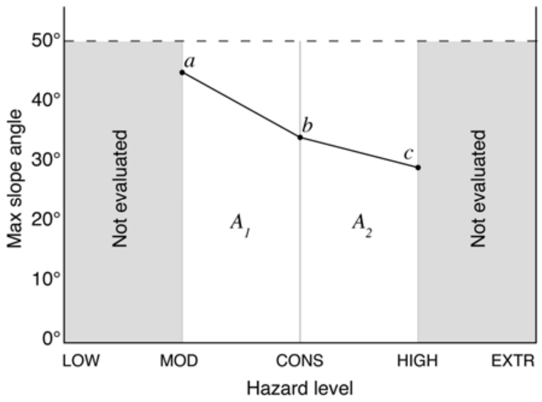

Figure 2. Slope-angle mobility for each framework was calculated as the area under the slope angle – hazard curve ($A_1 + A_2$). Variables *a*, *b* and *c* represent the maximum slope angle permitted under the framework threshold, either specified by the framework or determined from accident data.

gles are explicitly defined by the method; these angles were used directly to calculate slope-angle mobilities (Table 3). In the remaining cases, we used the maximum slope angle that existed in those accidents where the method would have indicated that the slope was unlikely to slide (a false negative result). To minimize outlier effects, we used the median value of the maximum slope angles where the slope angle distributions were not significantly different. Because the distributions were not all normal (the D-Agostino-Pearson probability of normality ranged from 0.54 to < 0.0001), we used the nonparametric Kruskal-Wallis test (or *H*-test) to assess differences.

4.2 Results & Discussion

Slope angle mobilities are shown in Table 3. Mobilities range from a maximum of 8.3 (NT, OC) to a low of 6.8 (Basic Reduction Method).

	Maximum slope angle			
Method	*Mod.*	*Cons.*	*High*	M_s
NT	48.0°	40.0°	38.0°	8.3
RMB	*39°*	*34°*	*29°*	*6.8*
RM.5	48.0°	*39°*	*29°*	*7.75*
RM1	48.0°	*39°*	*29°*	*7.75*
RM2	48.0°	*39°*	*29°*	*7.75*
SCY	48.0°	*35°*	*30°*	7.4
SCO	48.0°	*39°*	*30°*	7.8
OC3	48.0°	40.0°	38.0°	8.3
OC4	48.0°	40.0°	38.0°	8.3
n	167	12	12	
P	0.595	0.477	0.834	

Table 3. Slope-angle mobilities (M_s) of framework thresholds. Maxima in *italic* are specified by the method; other maxima represent the median value of maximum false-negative scores for the *n* samples. *P* is the *H*-probability of the sampled scores being from the same population.

As expected, mobility values correspond with the slope angle restrictiveness of the framework. For example, the Basic Reduction Method does not permit travel on or below certain slope angles at M, C and H hazards, and thus ranks lower than the NivoTest, or Obvious Clues methods which do not categorically prevent travel on steep slopes.

As a measure of absolute mobility, M_s is admittedly a rather low-resolution metric. It delineates general differences between methods but does not (due largely to small sample size for slope angle maxima) meaningfully distinguish between different threshold values of the same framework (e.g. RM, OC). Nevertheless, it provides a general measure of relative mobility that appears reasonable from a comparative standpoint.

5. EASE OF USE AND UTILITY

Even if a decision framework has a high preventive validity and provides for a lot of mobility, it will have little value to recreationists if it is difficult to use.

Ease of use is problematic to assess objectively because it depends largely on personal preference and the sensory-motor and cognitive orientations of a user. For example, users who are visually oriented may find the SnowCard the easiest of the frameworks to use, while numerically oriented users may prefer Reduction method. Furthermore, people are remarkably innovative and adaptive – it's difficult anticipate when a decision tool, which may be cumbersome to use at first, will become exceedingly efficient with practice.

For the individual user, a sound approach to determining ease-of-use among the various methods is to simply try them out and rank them according to personal preference. Here, we choose a 10-level ranking system where the most preferred framework has the highest rank.

Once the methods are ranked, a user now has a comparative measure of the three critical parameters for framework utility: preventive validity, mobility and ease of use. But which framework offers the best combination of these factors?

The answer, of course, depends on how important each of the three factors is to the user. Given a simple ranking of the relative importance of each of the three factors, a user can identify an optimal choice using a utility function that quantifies the user's overall satisfaction with a particular framework (Baron, 1994)

$$U_k = \sum_i w_i r_{k,i} = w_1 P_k' + w_2 M_{s,k} + w_3 E_k \qquad (4)$$

where P_k' is the preventive validity of the k^{th} framework adjusted to a 10-level comparison scale ($P_k \times 10$), $M_{s,k}$ is the slope-angle mobility of the framework, E_k is the ease-of-use rating of the framework, and w_1, w_2 and w_3 are the relative importance ranks of preventive validity, mobility and ease-of use respectively. For a given set of preferences, the framework with the highest utility value will provide the optimal combination of factors for that user.

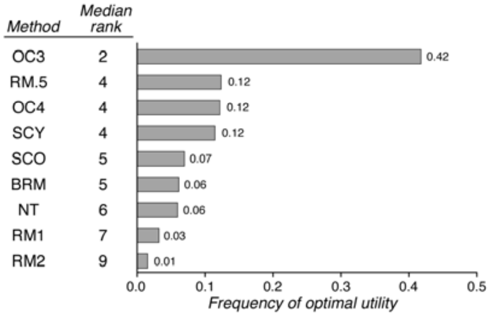

Figure 3. Frequency of optimal utility of the various frameworks evaluated across 3000 random sets of preferences. Decisions based on 3 obvious clues (Table 1) are most frequently optimal.

Every user will have a unique set of preferences and requirements regarding preventive validity, mobility, and ease of use, so it is clear that there is no single best framework that will fit all situations. But are some frameworks more frequently optimal than others?

We simulated the rankings across a large number of users by randomizing factor weights and ease-of-use preferences by maximizing the utility function of equation (4). This approach, implemented as a Monte Carlo simulation, yields the rank frequencies for each framework across a broad range of preferences. The frameworks which have the highest rank frequencies will be optimal most often.

Results of the simulation are shown in Figure 3. Rank frequencies converged to within 2% of their final values within 3000 iterations. The Obvious Clue method (threshold of 3 clues) was the optimal choice 42% of the time, by far the most frequent of any method. A similar pattern appeared in the median rankings of the methods across all simulation cases.

Despite incorporating a rather coarse approximation of mobility, the simulation results of Figure 3 have two important implications. First, it appears that very simple decision strategies are optimal across a large portion of potential users. Second, there are circumstances under which every framework represents an optimal balance of preventive validity, mobility and ease of use.

6. SUMMARY AND CONCLUSIONS

Several frameworks for making decisions in avalanche terrain are currently available to recreationists. In this study, we evaluated their performance against 751 avalanche accidents in the United States, and found significant differences in their effectiveness and utility.

Prevention - While all of the frameworks would prevent most accidents, the degree of prevention provided by customary thresholds in each framework varied by as much as 32%. Such differences remained even when mitigation measures such as exposing one person at a time and carrying beacons were included in the analysis. None of the frameworks showed significant sensitivity to the level of training of the accident party, their activity, or the type of slab released. Most of the methods showed significant sensitivity to avalanche climate, with the degree of prevention varying by as much as 23% (Reduction Method) across climates. In general, the frameworks were significantly more conservative in maritime ranges than in intermountain or continental ranges. With one exception (the Obvious Clues method), customary thresholds of the frameworks were ineffective at preventing accidents during periods of low or moderate hazard, ratings which include about 1 in 5 of all avalanche accidents.

Mobility - The range of terrain available under each framework is a critical factor in its overall utility. To assess mobility, we used an approximation based on the maximum slope angle permitted by the framework at the hazard levels where frameworks were most likely to be used by recreationists (moderate through high hazard). Although the approximation neglects factors such as aspect, elevation, snow conditions, and route finding skills, it showed a general ability to distinguish between frameworks. As expected, the frameworks that had no upper limits on slope angle (permitting, for instance, travel in protected or treed terrain during times of elevated hazard) exhibited the highest levels of mobility.

Ease of use - Frameworks that prevent accidents and allow liberal mobility will be of little value to recreationists if they are difficult to use. Determining which framework is easiest to use is largely a matter personal preference, and influenced greatly by the sensory-motor orientation of the user. We utilized a simple ranking system for ease of use attributes in the analysis, but made no objective assessments of the degree of ease of use in this study.

Utility – For any given user, the overall utility of any framework is a combination of its preventive validity, mobility and ease of use. The relative importance of each of these factors will change with each user. We approximated the preferences of a large number of users in a Monte Carlo simulation using a maximized utility function, and found that a method based on simple clues was optimal far more often than any other method. However, there are circumstances under which all of the frameworks represent an optimal choice.

In summary, we found that applying a checklist of seven simple cues (Table 1) to potential avalanche slopes represented the most effective decision strategy for avalanche terrain, based on accident data from the U.S. While the specific cues themselves warrant further investigation and refinement for use in North America, it is encouraging that such a simple approach appears to be so effective.

While preliminary, this finding is perhaps not so surprising. Recent advances in cognitive science have found that heuristic (simple cue) decision making is frequently optimal for novices facing complex decisions. And as every outdoor educator knows, it is usually more effective to give novices simple rules to follow than to give them complex decision algorithms.

Most avalanche accidents in the U.S. happened when the hazard was readily apparent, even to someone with minimal avalanche training. Thus, in order to reduce accidents and save lives, it appears that decision frameworks need only to identify fairly obvious conditions in a formal but simple way.

7. ACKNOWLEDGEMENTS

The authors would like to acknowledge the Colorado Avalanche Information Center for allowing access to their extensive accident records. We would also like to thank Werner Munter, Martin Engler and Robert Bolognesi for discussing their methods in detail with us.

Support for this research was provided by the NIF project for the development of an avalanche decision framework for amateur winter recreationists (Canadian Avalanche Association, Parks Canada), Snowpit Technologies, Avisualanche Consulting and the National Outdoor Leadership School.

8. REFERENCES

Atkins, D. and McCammon, I. 2004. Differences between avalanche experts and novices, *Proc. Int'l Snow Science Workshop*, Jackson, WY.

Baron, J. 1994. *Thinking and Deciding, 2nd ed.* Cambridge University Press, Cambridge, UK.

Bolognesi, R. 2000. NivoTest: a pocket tool for avalanche risk assessing. *Proc. Int'l Snow Science Workshop,* Big Sky, MT, USA, pp. 554-557.

Brugger, H. and Falk, M. 2004. Analysis of avalanche safety equipment for backcountry skiers, *Avalanche News* (66):34–38.

Engler, M. 2001. *SnowCard & Faktorencheck (Fachpublikation zu Risikomanagement – Lawinen; Info für Fachübungsleiter Nr. 24)*. Verlag Martin Engler, Sulzberg Germany.

Engler, M. and Mersch, J. 2000. *SnowCard: Lawinen –Risiko – Check*. Verlag Martin Engler, Sulzberg Germany.

Jamieson, B. 1994. Transceivers and avalanche survival, *Avalanche News* 42:8, Winter 1993/94.

Larcher, M. 1999. Stop or Go: Entscheidungsstrategie fuer Tourengeher. *Berg&Steig* 99/4, pp. 18-23.

McCammon, I. 2002. The role of training in avalanche accidents in the United States, *Proc. Int'l Snow Science Workshop*, Big Sky, MT, pp. 37–45.

McCammon, I. 2004. Heuristic traps in recreational avalanche accidents: Evidence and implications, *Avalanche News* (68):42–50.

McCammon, I. and Hägeli, P. 2004 (in preparation). *Analysis of existing decision support schemes for amateur winter recreationists.* Report for the Canadian Avalanche Association.

Mock, C. and Birkeland, K. 1999. Avalanche climatic regions of the western United States: An update, *The Avalanche Review*, 17(3): 6–7.

Munter, W. 2003. *3x3 Lawinen: Risikomanagement im Wintersport.* Third edition Agentur Pohl & Schnellhammer, Garmisch Patenkirchen, Germany.

Tremper, B. 2001. *Staying Alive in Avalanche Terrain*, The Mountaineers, Seattle, WA.

Tschiriky, F., Brabec, B. and Kern, M. 2000. Avalanche rescue systems in Switzerland: Experience and limitations, *Proc. Int'l Snow Science Workshop,* Big Sky, MT, USA, pp. 369–376.

	NivoTest			**Reduction Method**			**Reduction Method**						
	Score • 23			Basic			RR • 0.5			RR • 1.0		RR • 2.0	
	n	*X* ± CI	*P*	*n*	*X* ± CI	*P*	*n*	*X* ± CI	*P*	*X* ± CI	*P*	*X* ± CI	*P*
All cases	115	0.65 ± 0.08	-	280	0.80 ± 0.04	-	229	0.82 ± 0.04	-	0.60 ± 0.05	-	0.36 ± 0.06	-
Training			0.86			0.64			0.97		0.84		0.13
Unaware	24	-		61	-		52	-		-		-	
Aware	27	-		53	-		44	-		-		-	
Basic	33	-		66	-		42	-		-		-	
Advanced	30	-		38	-		23	-		-		-	
Activity			0.51			0.53			0.39		0.40		0.21
Ski	66	-		147	-		122	-		-		-	
Snowboard	11	-		21	-		19	-		-		-	
Snowmobile	10	-		61	-		48	-		-		-	
Climb	18	-		35	-		27	-		-		-	
Climate			**0.035**			**0.013**			**0.040**		**0.008**		**0.01**
Maritime	24	0.79 ± 0.16		56	0.89 ± 0.08		43	0.92 ± 0.07		0.79 ± 0.12		0.55 ± 0.15	
Intermountain	57	0.54 ± 0.13		112	0.72 ± 0.08		99	0.79 ± 0.06		0.56 ± 0.07		0.32 ± 0.06	
Continental	33	0.68 ± 0.16		91	0.81 ± 0.08		77						
Slab type			0.74			0.29			0.13		0.24		0.39
Hard	27	-		67	-		55	-		-		-	
Soft	62	-		135	-		120	-		-		-	
Wet	3	insuff. data		7	-		7	-		-		-	
Hazard			**<0.001**			**<0.001**			**<0.001**		**<0.001**		**<0.001**
Low	4	0.00		9	0.00		6	0.41 ± 0.37		0.00		0.00	
Moderate	26	0.40 ± 0.19		63	0.37 ± 0.12		53	0.60 ± 0.13		0.26 ± 0.12		0.05 ± 0.05	
Considerable	16	0.65 ± 0.24		57	0.91 ± 0.07		48	0.73 ± 0.13		0.46 ± 0.14		0.25 ± 0.12	
High	50	0.76 ± 0.12		151	0.98 ± 0.02		122	0.96 ± 0.03		0.84 ± 0.06		0.58 ± 0.08	
Extreme	6	0.68 ± 0.32		0	-		0	-		-		-	

	SnowCard					**Obvious Clues**				
		YEL		ORG			OC • 3		OC • 4	
	n	*X* ± CI	*P*	*X* ± CI	*P*	*n*	*X* ± CI	*P*	*X* ± CI	*P*
All cases	257	0.86 ± 0.04	-	0.75 ± 0.04	-	252	0.92 ± 0.03	-	0.77 ± 0.04	-
Training			0.93		0.32			0.43		0.98
Unaware	60	-		-		55	-		-	
Aware	35	-		-		30	-		-	
Basic	52	-		-		55	-		-	
Advanced	25	-		-		30	-		-	
Activity			0.36		0.49			0.73		0.34
Ski	131	-		-		118	-		-	
Snowboard	20	-		-		29	-		-	
Snowmobile	58	-		-		51	-		-	
Climb	30	-		-		29	-		-	
Climate			0.086		0.094			0.80		**0.006**
Maritime	56	-		-		55	-		0.90 ± 0.08	
Intermountain	106	-		-		111	-		0.72 ± 0.07	
Continental	84	-		-		78	-			
Slab type			0.26		0.16			0.60		0.54
Hard	59	-		-		49	-		-	
Soft	124	-		-		106	-		-	
Wet	7	-		-		9	-		-	
Hazard			**<0.001**		**<0.001**			**<0.001**		**<0.001**
Low	6	0.32 ± 0.32		0.00		7	0.63 ± 0.34		0.00	
Moderate	66	0.56 ± 0.12		0.25 ± 0.10		48	0.71 ± 0.13		0.36 ± 0.14	
Considerable	48	0.95 ± 0.05		0.85 ± 0.10		64	0.94 ± 0.05		0.83 ± 0.10	
High	137	1.00		0.97 ± 0.02		121	0.97 ± 0.03		0.91 ± 0.05	
Extreme	0	-		-		12	1.00		1.00	

Table 2. Statistical results from threshold comparisons. Here *n* is the sample size, *X* is the proportion of U.S. accidents prevented by the threshold, CI is the 95% binomial confidence interval, and *P* is the Pearson Chi-Square probability of the proportions being the same. Where $P < 0.05$, the categories have significantly different accident proportions and where *P* • 0.05, the category proportions are not significantly different from all the accidents of known score (top row).