DESCRIPTION AND EVALUATION OF EXISTING EUROPEAN DECISION-MAKING SUPPORT SCHEMES FOR RECREATIONAL BACKCOUNTRY TRAVELERS

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ABSTRACT

In recent years, a number of decision support frameworks have been developed in Europe to help recreationists recognize dangerous avalanche conditions. These frameworks generally fall into two categories: 1) knowledge-based strategies that help structure situational information, and 2) rule-based strategies that provide explicit algorithms for numerically rating the danger potential of a particular backcountry route or an individual avalanche path. Among the professional guiding community in Europe, rule-based frameworks have been somewhat controversial because of their reductionist nature, and because of questions regarding their applicability and accuracy in guided situations. But among European recreationists, rule-based systems have been generally welcomed because they offer clear and simple tools for navigating the complexities of decision making in avalanche terrain.

In North America, rule-based decision tools have attracted the interest of both recreationists and professional guides, particularly in the wake of several high-profile avalanche accidents. Unfortunately, it is not clear how applicable or effective European frameworks will be in the alpine regions of the United States and Canada. Differences in snow climate, terrain, recreation type, usage patterns, training and cultural factors are some of the issues relevant to the discussion of how rule-based decision systems might be adapted to North America. The discussion has been complicated by the fact that, to date, there has been no comprehensive analysis across these frameworks to assess their effectiveness.

The goal of this study was to evaluate the utility of existing rule-based decision frameworks for use in North American avalanche terrain. We examined a total of six frameworks: the Reduction Method, the Basic Reduction Method, the NivoTest, the Stop-or-Go system, the SnowCard and a simple checklist-sum method based obvious clues. The performance of each framework was determined by applying it to a database of 751 avalanche accidents that occurred in the United States during 1972–2004. The overall utility of each system was determined by three factors: preventive value, mobility, and ease-of-use.

Due to the lack of non-event data, we were unable to perform a conventional evaluation of the predictive value of each system. Instead, we calculated the preventive value, or the proportion of accidents that each framework would have prevented. Using binomial comparisons, we found that preventive values varied significantly by framework, ranging from about 60% for the Reduction Method to 92% for the checklist sum method. Preventive values were statistically invariant to the level of training of the accident party, the type of recreation activity, and the type of slab released by the accident. In contrast, preventive values were sensitive to snow climate, with most frameworks being significantly more conservative in maritime mountain ranges. The frameworks exhibited the highest preventive values during periods of considerable and high avalanche danger (about 80% of all accidents), but performed poorly (with the exception of the checklist sum method) during times of moderate and low danger.

For most recreationists and professionals traveling in avalanche terrain, the freedom afforded by a rule-based system is at least as important as its preventive value. In other words, a decision framework will not be particularly attractive if it reliably prevents accidents but restricts travel to low-angle terrain. We assessed the mobility afforded by each framework by calculating a simple measure based on the maximum slope angle allowed by the framework under various conditions. Calculated mobilities were the most restrictive for the Basic Reduction Method, and the least restrictive for the NivoTest and checklist sum method.

We modeled the overall effectiveness of each framework with a utility function calculated from the weighted preventive value, weighted mobility value and weighted ease-of-use value, which we modeled as a uniform probability distribution. To compare framework utilities, we used a Monte Carlo simulation across multiple (virtual) users, all of whom had specific but variable preventive value and mobility requirements, and randomly assigned ease-of-use preferences. Two important findings emerged. First, we found that there were specific circumstances and users for which each of the studied frameworks was optimal. Second, we found that the decision framework based on a simple checklist sum was optimal for the largest portion (54%) of simulated users. Even when combined with risk reduction measures such as wearing avalanche transceivers and exposing one person at a time to the danger, simple checklist-based methods appear to be superior to more complex decision support frameworks. This finding is consistent with recent cognitive research which suggests that simple, cue-based heuristic decision strategies are well-suited to efficient decision making, particularly by novices, in complex environments.

These findings suggest that simple checklists are a very promising area for further investigation and development of decision frameworks for avalanche terrain. While the exact definitions of the checklist items themselves warrant further investigation and refinement for use in North America, it is encouraging that such simple approaches appear to be so effective.

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PREFACE

Portions of this work were presented by the authors at the International Snow Science Workshop (ISSW) in Jackson Hole, WY, on September 22, 2004. The companion paper to the presentation may be found in the published proceedings. In addition, the authors have submitted a more detailed article for publication in a peer-reviewed journal.

Both the ISSW paper and the peer-reviewed paper focused primarily on a quantitative comparative analysis of the various decision support frameworks. This report presents a more comprehensive treatment of the subject, and includes the following supplementary information in addition to the original analysis:

- Detailed descriptions of each of the decision frameworks (Section 2),
- Explication of the preventive value parameter (Section 3),
- A comparison of the methods in terms of the 3x3 Formula (Appendix A),
- Invited comments by developers to the initial analysis (Appendix B),
- Our rejoinder to developer's and reviewer's comments (Appendix C).

Winter recreationists, alpine guides, snow safety professionals and other mountain users routinely face complex and critical decisions when safeguarding lives in avalanche terrain. With each tragic accident resulting in serious injury or death, the need for reliable decision tools to help manage avalanche risk becomes more pressing. Much work remains to be done, but we hope that others will find this report a useful early step in the evolution of robust decision frameworks for avalanche terrain.

ACKNOWLEDGEMENTS

The authors express thanks to Knox Williams, Dale Atkins, and the staff of the Colorado Avalanche Information Center in Boulder, Colorado for allowing access to their accident records, and for valuable supplementary discussions regarding the circumstances of many specific accidents. We would also like to thank Werner Munter, Martin Engler, Robert Bolognesi for discussing their methods in detail with us. Colani Bezzola, Robert Bolognesi, François Sivardière, Howie Schwartz, Jürg Schweizer, Stephan Harvey, Doug Fesler, Bruce Tremper, Laura Adams and Bruce Jamieson also provided valuable insights and comments.

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1. INTRODUCTION

In the late 1980s, a number of high-profile avalanche accidents in Switzerland prompted many people to question the effectiveness of traditional avalanche education. Did the training really help recreationists to make better decisions, or did it merely provide them with a primer in snow science, leaving them to sort out the complex and often ambiguous problem of avalanche prediction for themselves?

In an attempt to make the process of avalanche hazard evaluation more accessible to non-experts, Swiss mountain guide Werner Munter developed a system of easy-to-understand rules for making decisions in avalanche terrain. This system, known as the Reduction Method (RM), was formally introduced in 1997 and was primarily aimed at winter recreationists in the Swiss Alps. Munter's goal in developing and promoting this system was to reduce avalanche fatalities in Switzerland by fifty percent.

Soon after the introduction of the Reduction Method, other decision support frameworks appeared. Larcher (1999) presented the Stop-or-Go method (SoG); Bolognesi (1999b) introduced the NivoTest (NT) and Engler and Mersch (2000) developed the SnowCard (SC). These methods were generally well received by recreationists, but their introduction created controversy among the professional avalanche community in Europe. Professional guides in particular debated how such decision tools, which were primarily aimed at novices and recreationists, might apply to their own actions when traveling in avalanche terrain while guiding clients. It was not clear if these decision tools would come to represent an informal standard of decision-making against which professional decisions might be compared, or if they were a decision strategy that was uniquely suited for non-professionals. To complicate matters further, there existed no quantitative data on how successful these systems were in predicting avalanches, how often they prevented accidents, and how frequently they unnecessarily turned users away from slopes that posed no significant avalanche hazard. Comparative analyses were mostly anecdotal or speculative in nature, and as of this writing, the authors are aware of no systematic review of these decision frameworks or comparative studies of their effectiveness.

Due primarily to the lack of descriptive literature in English, these decision support frameworks have so far not been widely adopted in North America. Here, there is growing interest among recreationists for simple, rule-based decision tools for avalanche terrain, and concern among professional guides regarding prescriptive standards for traveling with clients. The major avalanche winter of 2002/03 in Western Canada highlighted these issues, and interest in decision frameworks that apply in North America has intensified.

The purpose of this study was to evaluate four European decision frameworks (and one very simple decision framework), for their applicability to users in North America. In this study, we evaluated the utility of each framework as a function of three attributes: 1) prevention value, or the proportion of accidents that each framework would have prevented, 2) mobility, or the range of terrain accessible under each framework, and 3) ease of use. We also evaluated the frameworks in conjunction with two common hazard mitigation measures: carrying an avalanche beacon and exposing only one person at a time to the hazard.

2. DESCRIPTION

Decision support frameworks for recreational users in avalanche terrain typically fall into two general categories: knowledge-based systems and rule-based systems. In knowledge-based systems, decision makers have a conceptual structure into which they can organize information relevant to the avalanche danger. At various decision points on a tour, the structure acts as a kind of open-ended checklist to ensure that no critical information has been overlooked in trip planning, route selection or slope management. The use of a knowledge-based system typically culminates in an overall assessment of the avalanche danger, leading to a go/no go choice from among a set of options regarding possible trips, available routes, or particular slopes.

Two of the most commonly used knowledge-based decision systems are the 3x3 formula and the avalanche triangle. In the 3x3 formula (Appendix A: Munter (1992; 1997a; 2003a), users organize information into a 9-element grid by three spatial categories (regional, local, and slope-specific) and three type categories (snowpack/weather, terrain, and human factor). Users proceed through the spatial categories using a number of guide questions, filling in relevant information as they go to arrive at (what are hoped to be) sound decisions at various decision points in the trip.

The avalanche triangle (see, e.g., Fredston and Fessler, 1999) is another well-known knowledge-based decision framework that is currently taught in many North American recreational avalanche schools (e.g., CAA, 1998). The avalanche triangle organizes information into four categories: snowpack, weather, terrain and human factors. The method also provides a qualitative checklist (Fredston and Fesler, 1999: 87) that allows recreationists to rate each element of the triangle as red, yellow, or green. As with the 3x3 formula, the avalanche triangle is intended to assist go/no go decisions at various points during a trip through avalanche terrain.

Knowledge-based decision systems offer a number of advantages as tools to facilitate decisions, including: 1) they help users easily discern relatively dangerous and relatively safe conditions, 2) they give users a common vocabulary to discuss risk in avalanche terrain, and 3) they give teachers of avalanche courses a way of structuring the complex information that is relevant to decision making in avalanche terrain.

Some of the disadvantages of knowledge-based systems include: 1) they lack stopping rules for information gathering, that is, they provide little guidance on how much information is adequate in each category, 2) they generally provide no guidance for dealing with ambiguous or conflicting information, and 3) they provide no guidance on the relative or absolute importance of information. These disadvantages tend to be most pronounced for novice users, who ironically are in the most need of decision support when traveling in avalanche terrain.

Ultimately, knowledge-based decision frameworks are useful tools in the hands of knowledgeable users, but less so in the hands of novices. The use of these tools is complicated by the fact that even experienced users may reach very different conclusions about the stability of a slope. Furthermore, a number of well-known cognitive biases can have profound effects on subjective probability assessments, often without the decision maker being aware of it (McCammon, 2000). For these reasons, a comprehensive performance comparison of knowledge-based decision systems is highly problematic, and we do not attempt one here.

The second type of decision framework for avalanche terrain, rule-based systems, uses very specific methods and numerical thresholds for making go/no-go decisions. The remainder of this section describes the background, history and usage of the main European rule-based decision support schemes. In addition to these methods, we also review a simple checklist sum framework for comparison.

It is important to note that the methods described here typically have a knowledge-based component and a rule-based component, and that these components are intended to be used together when making decisions regarding avalanche hazard. Both components for each system are described below. But in the subsequent analysis, we focus exclusively on the rule-based components so that the various frameworks can be quantitatively compared.

2.1 Reduction Method (Munter)

As discussed in the previous section, the 3x3 formula is intended to be used by decision makers to illuminate critical factors indicating the degree of avalanche hazard. But in most cases, proper interpretation of the collected information often requires substantial knowledge, extensive practical experience, or both. In order to allow less experienced recreationists to safely venture into avalanche terrain and thus gain experience with less chance of mishap, Munter introduced the Reduction Method (Munter, 1997a; 1997b; 2003a) as a control instrument to double check decisions and to prevent the most serious planning mistakes. During each evaluation step of the 3x3 formula, the Reduction Method is used to check the decision. To proceed with the intended trip, two “go” results are needed at each of the three steps.

The underlying assumptions for the development of the Reduction Method were: 1) the nivological information contained in the avalanche bulletin should be sufficient for accurate decision making, 2) extra snow study skills or specialized equipment should not be required, 3) the decision making focus should remain on terrain selection, and 4) the method should be relatively simple. The goal of the system was to reduce avalanche fatalities without unnecessarily restricting recreational activities. Acceptable risk in the system was defined to be equivalent to the risk of dying in an auto accident in Switzerland, which meant that Swiss avalanche fatalities had to be reduced by 50% from their 1997 levels.

Based on the avalanche danger rating of the public avalanche bulletin, the Reduction Method assigns a danger potential to the current likelihood of triggering an avalanche. The danger potential suggested by Munter (Table 1) is based on a study of rutschblock scores (Munter, 1992, 1997a; 2003a), which showed that the proportion of weak scores doubles from one danger rating to the next. This result was interpreted by Munter to be an indication that the surface area of weak spots (potential trigger points) increased exponentially with avalanche danger. Munter reasoned that the danger potential represents the probability of hitting an existing weak spot and triggering an avalanche.

Table 1:
Danger potential for different danger ratings

Danger rating	Danger potential
Low	2
Moderate	4
Considerable	8
High	16
Extreme	n/a

By applying a number of safety measures under the Reduction Method, backcountry travelers can reduce their avalanche risk. These so-called reduction factors (Table 2) are categorized into three different classes. First-class reduction factors (RF_1) are concerned only with slope incline. Under considerable or high danger ratings, the method dictates that a first-class reduction factor must be applied. The numerical values of this reduction factor class are reportedly based on an examination of 91 Swiss avalanche incidents. Approximately 50% of these accidents happened on slopes steeper than 39°, 35% on slopes between 35° and 39° and the remaining 15% occurred on slopes less than 35° (Munter, 2003a). Therefore, by getting users to avoid slopes steeper than 39°, Munter believed that half of the examined incidents could have been prevented. Munter maintains that this is equivalent to reducing the risk by 50%, or a risk reduction factor of 2. Second class reduction factors (RF_2) address slope aspect, elevation and usage. The numerical values for the slope aspect reduction factors are based on the results of the MISTA research project. Fifty percent of all weak test scores were found in the northern quadrant (NW-N-NE), 75% in the northern sector (WNW-N-ESE). Third class reduction factors (RF_3) are concerned with group size and group management aspects. In addition to the reduction factors, the Reduction Method includes supplementary rules that apply under certain con-

Table 2:
Reduction factors in the Reduction Method

		Reduction factor	Value
1st class	Nr. 1 or	steepest section below 40°	2
	Nr. 2 or	steepest section 35°	3
	Nr. 3	steepest section below 35°	4
2nd class	Nr. 4 or	avoid northern quadrant (NW-N-NE)	2
	Nr. 5 or	avoid northern sector (WNW-N-ESE)	3
	Nr. 6	avoid aspects and elevation band specifically mentioned in avalanche bulletin	4
	Nr. 7	continuously used slopes	2
3rd class	Nr.8 or	large group (>4) spaced out	2
	Nr. 9 or	small group (2-4)	2
	Nr. 10	small group spaced out	3

ditions. For example, if the advisory mentions all aspects to be dangerous, reduction factors 4 to 6 are not to be included in the formula.

Reduction factors are combined and the residual risk can be quantified with the equation

$$\text{Residual Risk} = \frac{\text{Danger Potential}}{\prod_i RF_i} \leq 1 \tag{1}$$

where the numerator is simply the danger potential derived from the avalanche bulletin (Table 1) and the denominator represents the product of all reduction factors that apply (Table 2).

To reduce the avalanche risk to an acceptable level, Munter suggests a residual risk of 1 for recreationists. The risk equation allows experimentation with different reduction factors to determine the combinations of terrain choices and group behavior that minimize avalanche risk under specific hazard conditions.

Certain combinations have proven to be particularly accident prone. An example is the ‘deadly threesome’ (considerable danger; slope steeper than 39°; northern quadrant), which was responsible for more than 50% of all Swiss avalanche accidents in the winter of 1996/97 (show for winter 96/97 in Munter, 2003b). Munter also suggests the following combinations as absolute upper limits (Munter, 2003a p. 129):

- Moderate danger; slope 35°-39°; northern quadrant; infrequently skied
- Considerable danger; slope 35°-39°; all aspects (except for frequently-skied runs)
- High danger; slope less than 30°; all aspects

Munter maintains that these limits do not have any safety margins and he recommends that they not be exceeded under any circumstances, even by professionals. He likewise defines a residual risk of 2 as an upper limit for the risk equation, which he reports is equivalent to the average residual risk of fatal avalanche accidents in Switzerland (Munter, 2003a p. 194).

In order to make the Reduction Method more attractive for novices, Munter has introduced several simplifications. The Elementary or Basic Reduction Method focuses exclusively on slope angle and discourages backcountry users from traveling in certain terrain depending on the danger rating (Munter, 1992 p. 133-134 (initial idea); 1997a; 2003a):

- Moderate danger level: no travel on slopes steeper than 39°
- Considerable danger level: no travel on slopes steeper than 34°
- High danger level: no travel on slopes steeper than 30°
- Extreme danger level: avoid backcountry travel

Other simplifications include the Golden Rule (Munter, 2003a p. 127) and the Decision Matrix (Munter, 2003b). Both approaches are non-mathematical formulations of the regular Reduction Method, intended to make the system more appealing to novice users.

One frequent criticism regarding the derivation of the Reduction Method concerns the lack of backcountry usage data, or the total number of recreational outings in avalanche terrain. With only accident data at hand, it is not possible to do a proper risk analysis for avalanche incidents. This shortcoming is clearly acknowledged by Munter (1997a; 2003a). We discuss the issue of non-event data, which has important implications in framework design, in Section 3.

Since its introduction, the Reduction Method has received a lot of publicity and has been intensely debated among professionals in alpine countries. During these debates, the Reduction Method has been at times erroneously represented as an exclusive tool for avalanche hazard evaluation, rather than as a control instrument for decisions made using the 3x3 Formula. Both of Munter's methods (Munter, 1997a; 2003a) are officially recognized and recommended by the UIAGM (International Union of Mountain Guide Associations) and the UIAA (International Union of Alpine Associations). The 3x3 Formula is well established and is an integral part of many avalanche awareness programs in alpine countries. The Reduction Method is most established in Switzerland, where is it is strongly promoted by the Swiss Alpine Club (SAC).

However, only a modified version of the Elementary Reduction Method is currently part of the regular avalanche safety curriculum at the recreational level (see, e.g., SLF, 2003). This modified Elementary Reduction Method includes the so-called ‘1-Step Rule’, which allows users to reduce the danger rating by one step in areas (aspect and elevation ranges) that are not explicitly mentioned in the avalanche bulletin report. In 1998, a panel of Swiss avalanche educators decided that the equation of the Reduction Method allows too much room for interpretation and therefore misuse. They concluded that only the Elementary Reduction Method should be taught in the mountain guide courses and the method should primarily be presented as a planning tool (Harvey, 2005).

The only formal documentation of Munter’s methods that is currently available in English is the book by Kurzeder and Feist (2003). The chapter on decision-making relies heavily on Munter’s approach, and appears to be largely consistent with Munter’s earlier descriptions of the methods. Experienced recreationists and avalanche workers may find the book to be a helpful reference to Munter’s ideas, but novices in particular may find the section on decision making somewhat confusing, since it is not always clear that the 3x3 Formula and Reduction Method are complementary tools. An English translation of the 2003 edition of Munter’s book had been scheduled for publication during the 2004/05 winter season, but as of this writing, the publication schedule for an English version of Munter’s book appears uncertain.

2.2 Stop-or-Go (Larcher)

In his role as the overseer of education in the Austrian Alpine Club (OeAV), Michael Larcher reported experiencing some practical difficulties when working with Munter’s Reduction Method (Larcher, 1999; 2000). He felt that the necessity of working out a mathematical equation posed an obstacle to widespread acceptance of the method among practitioners and recreationists. He also felt that the Reduction Method did not directly include more traditional evaluation knowledge in the decision-making strategy. With the Stop-or-Go card (Figure 1) Larcher (1999; 2000) proposed a simple, step-by-step decision-making strategy that helped backcountry travelers focus their attention on crucial factors contributing to avalanches. The method consists of three components. The first two, Check 1 and Check 2, form the actual decision-making framework, while the third component presents standard mitigation measures that should be followed regardless of the avalanche danger rating. The primary target audience of the Stop-or-Go card is advanced recreationists who are willing to take a three to six day course on avalanche safety.

Check 1 applies the Basic Reduction Method, which simply restricts travel to terrain less than a certain steepness depending on the avalanche danger rating indicated in the bulletin (see previous section). In order to give users more tangible rules for estimating slope inclines, the method suggests that the necessity of kick-turns during ascending can be used as a rule of thumb to identify slopes steeper than 30°. Hence, "kick-turn terrain" should be avoided under high avalanche danger conditions.

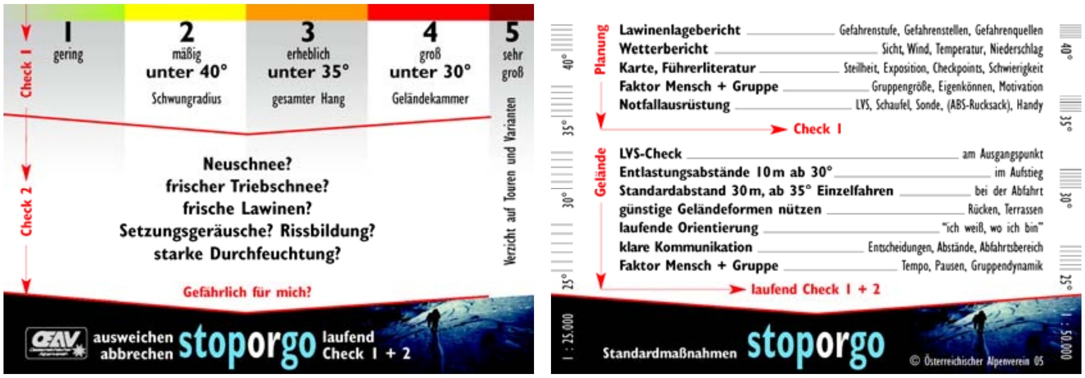

Figure 1: Front and back of Stop-or-Go card (3rd Edition, 2004; reproduced with permission of M. Larcher and OeAV)

Check 2 provides backcountry travelers with a series of questions that help direct their attention to the most crucial factors contributing to avalanche hazard. The goal is to raise the situational awareness of the user by providing clear instructions. Check 2 consists of three steps: First, the user must recognize potentially dangerous conditions. The five contributing factors addressed by the method are 1) new snow, 2) snow drift, 3) recent avalanche activity, 4) water saturation and 5) evidence of collapsing in the snowpack. Second, the user must determine whether the conditions observed currently pose a threat to the group. Larcher (2000) acknowledges that this step is quite vague and requires a considerable amount of training and practical experience. However, he views this uncertainty as inherent in the avalanche forecasting process, and more realistic than the very strict rules of the Reduction Method. Lastly, users have to act upon their assessment. If the analysis revealed a potential threat, the backcountry traveler must stop and reconsider their route. Either the observed conditions require a change of plans or the trip has to be completely abandoned. If the method reveals no apparent danger, travelers can proceed with their route as planned.

Larcher (1999; 2000) stresses that no decision in avalanche terrain can provide complete safety. To provide an additional safety net, the Stop-or-Go method recommends well-known hazard mitigation measures for the planning, ascent and descent stages of a trip. These recommendations generally follow the 3x3 Formula progression. Examples include testing avalanche beacons at the beginning of the ascent, prudent route selection, and establishing clear communication among group members during descents.

The Stop-or-Go method has been primarily adopted by the Austrian Alpine Club (OeAV), but documentation of the method has so far been very limited. In addition to magazine articles by Larcher (1999; 2000; 2001), there is a training video (Larcher and Putscheller, 2000) that explains the usage of the method with an example. There is currently no documentation available in English.

2.3 SnowCard and FaktorenCheck (Engler)

One criticism of the Reduction Method has been that it does not specifically accommodate users with advanced snow science knowledge and refined route finding skills. Martin Engler’s goal for the SnowCard and Faktorencheck was to develop a risk management tool that not only promoted the development of avalanche assessment skills (Engler, 2001b), but could be adapted to the needs of more skilled users. The method is intended to provide useful decision-making guidance for all user levels ranging from beginners to experts.

Engler's method is primarily based on Munter's 3x3 Formula. The sequential checklists of Engler's method ensure a comprehensive evaluation from the trip planning stage to the assessment of an individual avalanche slope. At each stage, the SnowCard and Faktorencheck provide tools for making decisions based on the collected information.

The SnowCard (Engler and Mersch, 2000) consists of two charts printed on a lenticular card[1] showing avalanche risk in different colors as a function of danger rating (low to high) and slope incline for favorable and unfavorable slopes (Figure 2). Based on the danger rating in the public avalanche bulletin and the steepest portion of the relevant slope, the user determines the avalanche danger using the charts. The relative location or proximity of the slope is a function of the danger rating. During low danger rating the relevant slope angle is the portion close to the traveler's track, while under moderate danger rating the relevant slope angle is the area within 20-40 m of the track. Under considerable avalanche danger the area extends to the entire slope and under high danger it also includes adjacent slopes. In the case of frequently used slopes, the incline value can be reduced by 4 or 5°. The SnowCard represents the risk with a color sequence from green to yellow to red. Within the green region accidents are relatively rare and travel is generally safe. The red region represents an absolute limit and travel on these slopes is only recommended under special circumstances. Within the yellow region extra precautions are recommended, such as limiting group size and allowing for sufficient spacing between party members.

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[1] A lenticular card displays multiple images (two, in the case of the SnowCard) depending on the angle of view. The SnowCard also incorporates a simple inclinomoter.

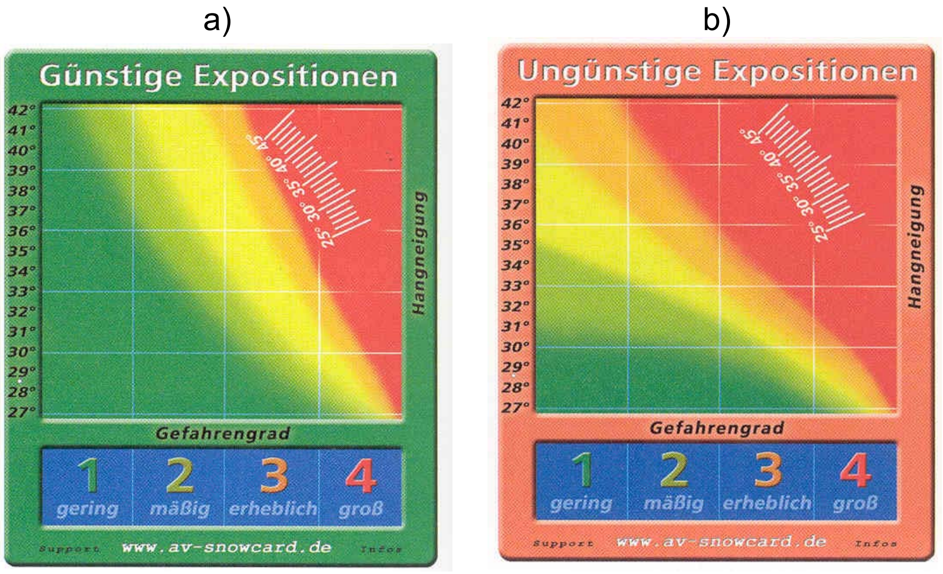

Figure 2: SnowCard lenticular images for favorable (a) and unfavorable (b) aspects (Engler and Mersch, 2000).

The transition between the different colors on the SnowCard was intentionally made fuzzy by its developers to alert users to the probabilistic nature of avalanche forecasting. The gradual changes allow users to easily choose routes according to their personal risk level. While a more conservative backcountry traveler might choose the yellow-orange boundary for no-go decisions, a more aggressive user might only use the orange-red line as an absolute limit.

The boundaries between the different colors are reportedly based on Engler's personal experience, and they are intended to represent generally accepted behavior in avalanche terrain (Engler, 2001b). In addition, Engler (2001) also conducted a limited statistical analysis of avalanche incidents. The analysis confirmed the exponential growth of the risk potential seen in Munter's work by scaling the number of avalanche accidents with the frequency of the different danger ratings (only for danger ratings low to considerable; there was insufficient data for high and extreme conditions). The analysis also points out the high reliability of the aspect and elevation information provided in Swiss avalanche bulletins. The color boundaries were also calibrated to match other rule-based decision-making methods, such as the Elementary Reduction Method in the case unfavorable aspects.

Even though avalanche bulletins in Europe are generally of high quality, a detailed local examination of the main avalanche factors by an experienced user can generally provide a more reliable assessment of the avalanche conditions on a particular slope. The Faktorencheck is a checklist which allows a comprehensive and objective examination of five (or seven) main factors contributing to avalanche incidents (Engler, 2001b; a). The first three factors are concerned with the last snowfall period and new snow instabilities: How much did it snow over what period? Was there any significant snowdrift and over what time? What was the temperature development during the snowfall? The next two factors examine persistent instabilities by asking questions about the characteristics of the old snow surface and the stability of the underlying old snowpack. The final two factors (only mentioned in Engler, 2001b) examine detailed terrain characteristics of the route and assess human factors influencing the decision-making process. Examples are interfering group dynamics or conflicting personal agendas. Each of these factors is individually evaluated and the associated risk regarding avalanche incidents is quantified on a scale from very unfavorable to very favorable. Detailed explanations for the rating of each of these factors is given in Engler (2001; 2001a). The presence of one or more unfavorable factors generally suggests that avalanches are highly probable.

An important feature of Engler’s method is that the different user levels build on one another. At the simplest level (A-1), a minimum of information and experience is assumed. The only information used is the danger rating and slope incline. The most conservative case is assumed at this level and only the graphic for unfavorable slopes is used for decision-making. To ensure the validity of the bulletin rating, backcountry travelers are asked to pay attention to obvious alarm signs such as collapse noises (i.e. whumpfs), significant snow drifting, intense snowfall, substantial amounts of new snow and recent avalanche activity. At this level, the presence of any of these alarm signs should be interpreted as a sign of considerable avalanche danger, and travel in avalanche terrain is not recommended. At the basic level (A-2) the user is expected to completely understand the detailed information provided in avalanche bulletins. The additional details about aspect, elevation and shape enable the backcountry traveler to classify the terrain into favorable and unfavorable slopes and use both SnowCard charts. The basic level recommends that information from the bulletin should always be verified locally and alarm signs should be continuously checked for locally higher avalanche danger. At the advanced level (B), the more experienced user is able to locally verify the danger rating of the bulletin by examining the first three aspects of the Faktorencheck. If, contrary to the information given in the avalanche bulletin, there are no indicators for new snow instabilities, the danger rating of the bulletin can be locally corrected downward by at most one danger rating. At the expert level (C), users are able to comprehensively check the bulletin rating, including persistent instabilities, or establish their own danger rating by performing a complete Faktorencheck.

The Faktorencheck builds on the assumption that the danger ratings given in bulletins address the worst conditions expected. While alarm signs are continuously checked to ensure that the true danger level is not above the bulletin danger rating, a deeper understanding of alarm signs allows more experienced users to identify slopes with relatively higher stability (A-2: recognition of favorable slopes based on bulletin information; B: local downward correction of the danger rating regarding new snow instabilities; C: local downward correction of the danger rating regarding new snow and persistent instabilities). This is intended to allow the experienced user increased latitude in choosing potential travel routes, a feature which is intended to encourage some recreationists to deepen their understanding about avalanches. The Faktorencheck level used depends not only on the user’s experience, but also on the amount of information available at the time. Under poor visibility conditions, for example, when it is not possible to examine the factors of the Faktorencheck, even highly experienced users are encouraged revert to using the method at the basic level.

The SnowCard and Faktorencheck are currently supported by the German Ski Association and have been widely adopted by the German Alpine Club (DAV). In their avalanche awareness courses, the method is taught as a decision-making tool within the framework of the 3x3 formula (Engler, 2001b).

Currently, there is no documentation of the SnowCard or Fakorencheck available in English. In addition to the books and brochures mentioned in the text, information in German can be found on the Internet at www.av-snowcard.de.

2.4 NivoTest (Bolognesi)

The frameworks described so far require an accurate, local avalanche bulletin as an input into the framework. But when avalanche bulletins are intended for large areas they tend to, by necessity, describe avalanche conditions in relatively general terms. The NivoTest (Bolognesi, 2001) is a tool that is designed to allow backcountry travelers to re-evaluate bulletin information and do a focused assessment of the avalanche risk for a specific route or terrain feature (Figure 3). While the preceding frameworks are intended to be used during all trip stages, the NivoTest was specifically designed to address the local scale of the 3x3 Formula (Bolognesi, 2003).

The NivoTest consists of 25 yes or no questions regarding weather, snowpack conditions, avalanche activity, intended route and participants (Table 3). Each question corresponds to a weighting value that is nominally based on the probability of avalanches and the vulnerability of the group. In the initial stages of NivoTest development, the weighting value for each factor was based on a statistical analysis of the NivoLog dataset[2]. After the initial analysis, some of the highly important factors, such as snow drift, were divided into two separate questions (e.g. questions #3 and #10 in Table 3) to minimize the effect of an

---

[2] NivoLog is a support system for avalanche safety programs that has been in operational use in several ski resorts for over 15 years (Bolognesi, R., 1998. NivoLog: An avalanche forecasting support system. *Proceedings of International Snow Science Workshop*, *Sunriver, OR*. 412-418, Bolognesi, R., 1999. *NivoLog 3.0 (product brochure)*. [available from Meteorisk, Rue de l'Avenir 11, CP 993, 1951 Sion, Switzerland].). At the time of the NivoTest's development, the dataset contained approximately 7000 cases including avalanche and non-avalanche events (Bolognesi, 2000).

NivoTest™

Aide à l'estimation du risque avalanche sur un itinéraire en montagne
Recommandé par Jean Troillet, guide, 1er snowboarder à l'Everest

	SI OUI :
Pluie au cours des 2 derniers jours ?	+3
Chute de neige > 20 cm au cours des 3 derniers j. ?	+3
Transport de neige (vent) au cours des 5 derniers j. ?	+3
Température de l'air > 0°C ?	+1
Visibilité réduite (nuit, brouillard) ?	+3
Neige profonde (enfoncement piéton: 20 à 40 cm) ?	+3
Neige très profonde (enfoncement piéton: 40 cm et +) ?	+5
Neige mouillée ?	+2
Manteau neigeux irrégulier (épaisseur ou structure) ?	+1
Congères ou corniches ?	+5
Couche interne fragile * ?	+3
Avalanche survenue au cours de la journée ?	+4
Avalanche survenue la veille ou l'avant-veille ?	+2
Fissures dans le manteau neigeux ?	+1
Itinéraire sans abri ?	+4
Itinéraire exposé (barres, crevasses, séracs) ?	+1
Itinéraire peu fréquenté ?	+1
Itinéraire comportant des pentes raides (30° et +) ?	+4
Itinéraire dominé par des pentes raides (30° et +) ?	+2
Pentes raides convexes ?	+1
Participant de faible niveau technique ?	+1
Participant en mauvaise condition physique ?	+1
Participant non équipé de pelle, sonde et ARVA ?	+1
Groupe de + de 5 personnes ou de - de 3 pers. ?	+1
Groupe non entraîné au secours ?	+1

* probable après un grésil, un givrage -ou, sur les versants peu ensoleillés, après une période de temps clair et froid.

200217 NATHAN

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www.Alpitude.com

Indication valable seulement si une réponse a été apportée à chaque question !

☹ La situation est délicate. Il est préférable de renoncer provisoirement à l'itinéraire envisagé à moins d'être **très** expérimenté.

😐 La situation est suspecte. Ne parcourir l'itinéraire que très prudemment. Eviter tout passage exposé et progresser un à un, d'abri en abri.

☺ La situation *semble* sûre mais se méfier d'éventuelles instabilités ponctuelles et surveiller l'évolution des conditions. Rester vigilant !

DANS TOUS LES CAS : ne jamais s'engager dans une zone interdite ; ne pas partir seul ; consulter les bulletins météorologiques, les bulletins avalanches et les informations locales ; utiliser un matériel adapté, et vérifier son parfait état avant le départ ; indiquer son itinéraire à une personne de contact ; prendre le temps d'observer et d'analyser ; suivre les consignes du plus expérimenté ; ne pas progresser groupés ; éviter impérativement toute zone dominant des lieux fréquentés ; redoubler de prudence si l'on est encordé ; prévenir en cas de retard ; solliciter les professionnels : gardiens de refuges, guides de montagne, pisteurs secouristes et moniteurs de ski.

CONSIDERER QUE LE RISQUE ZERO N'EXISTE PAS !

OCVS
Organisation Cantonale Valaisanne des Secours

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MAISON FRANÇOIS-XAVIER BAGNOUD DU SAUVETAGE

Usage réservé aux personnes initiées sous leur seule et entière responsabilité. Lire la notice et les ouvrages spécialisés.

Figure 3: Front and back of NivoTest (Bolognesi 2001).

accidental oversight. In the product testing phase, the NivoTest was given to professionals for testing and fine-tuning the weighting values. The weights for the last five questions regarding group members were reportedly based on the developer's personal experience. The low weights of these questions have the effect that these aspects only play primary roles in the decision making in situations that are close to the decision thresholds. However, having these questions included in the decision tool has the potential to raise the general awareness of recreationists towards these aspects.

When assessing the avalanche risk with the NivoTest, backcountry travelers must answer 25 questions for each route, slope or terrain feature. For each "yes" answer, users add the associated weight to the cumulative sum by turning a rotary dial. After answering all questions, a comprehensive risk assessment appears in a window on the back side of the card in the form of one of three icons: a smiling face, an uncertain face, and a sad face. The smiling face corresponds to an overall Nivotest score less than 9, and indicates that

Table 3:
NivoTest questions

	No.	NivoTest question	Value
Weather	1	Did it rain during the last two days?	+3
	2	More than 20cm of new snow during last three days?	+3
	3	Snow drift during the last five days?	+3
	4	Air temperature above freezing (>0°C)?	+1
	5	Poor visibility (night, fog)?	+3
Snowpack	6	Deep snow (foot penetration between 20 and 40cm)?	+3
	7	Very deep snow (foot penetration more than 40cm)?	+5
	8	Moist or wet snow?	+2
	9	Irregular snowpack (thickness and/or structure)?	+1
	10	Pillows of drift snow or cornices?	+5
	11	Buried persistent weak layers? (highly likely after graupel, after a crust or after a clear and cold period on shady aspects)	+3
Aval.	12	Avalanche activity today?	+4
	13	Avalanche activity yesterday or day before?	+2
	14	Visible cracks in snowpack?	+1
Route	15	Exposed route without protected areas?	+4
	16	Dangerous route (e.g., cliffs, crevasses, seracs)?	+1
	17	Unusual, infrequently traveled route?	+1
	18	Route with steep slopes (≥30°)?	+4
	19	Steep slopes (≥30°) above the route?	+2
	20	Steep convex rolls?	+1
Participants	21	Participants with low technical skills?	+1
	22	Participants in bad physical shape?	+1
	23	Participants with avalanche safety equipment (transceiver, probe, shovel)	+1
	24	Group size >5 or <3?	+1
	25	Group not trained in avalanche rescue	+1

conditions are generally safe. The NivoTest card recommends that under these conditions, backcountry travelers should be alert for local instabilities and changing conditions. The uncertain face corresponds to a NivoTest score between 9 and 23, and indicates suspect conditions. Under these conditions, it recommends that recreationists avoid exposed locations and proceed one at a time in exposed areas. The sad face corresponds to an overall score greater than 23, and indicates highly unstable conditions. Under these conditions, the NivoTest advises travelers to abandon the planned trip or avoid the terrain feature, unless the group has appropriate knowledge of the local snowpack and the skills to manage a higher level of avalanche hazard.

In addition to the 25 specific questions, the NivoTest also provides a list of useful information resources and safe travel practices. There is also space on the card for written notes such important phone numbers. Users can also add their own questions and can modify the weights of the existing questions (Sivardière, 2003). The NivoTest provides a flexible platform for decision-making that can be adjusted individually to the specific local conditions or the experience level of the user. However, the NivoTest gives no explicit criteria for identifying which threshold values might apply to which users or locales, nor does it specify when adjustments to the weighting factors might be appropriate. Like the other decision support frameworks described above, deviations from or modifications to the basic framework are up to the subjective judgment of individual users.

Robert Bolognesi, the developer of the Nivotest, reports (Appendix B):

> *The NivoTest is used in France, in Italy, in Spain and in the French part of Switzerland. It is supported by the French Alpine Club, by the State Rescue Organization OCVS, by the Ski Patrolmen Association of the French and Italian parts of Switzerland and by the Italian Alpine Club. It is distributed by the French National Association for Snow and Avalanche Studies (ANENA) with the agreement of its affiliates: Météo-France, CEMAGREF, French Mountain Guides Association, French Ski Instructors Association, Safety Services Chiefs Association, etc.*

With the exception of Bolognesi (2000), there are currently no English publications describing the NivoTest. Information in French is available at http://www.meteorisk.com.

2.5 Checklist Sum or Obvious Clues

In discussions about the previously described decision support frameworks, a common point of interest is how these systems might perform compared to a simple checklist of easily-observed avalanche signs. Table 4 presents such a checklist, where a user simply adds up the number of obvious clues that apply to the slope in question. The cumulative sum gives a rough estimate of the relative likelihood of an avalanche occurring. Originally developed as a quantitative measure of exposure for studies on decision making of avalanche victims (McCammon, 2000, 2002, 2004), it is included here for comparison purposes as representative of a class of very simple decision aids. The method incorporates some aspects of a simple knowledge-based system but still provides the quantifiable parameters of a rule-based system. The acronym ALP TRUTh is a handy memory aid for recalling each of the seven clues. Discussions of the rationale of this method can be found in McCammon (2000; 2004) and Atkins and McCammon (2004).

Table 4:
Obvious clues for the checklist sum method

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 danger rating 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.

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

3. GENERAL METHODS

3.1 Nature of the variables

From a conceptual standpoint, the proposition of a decision support system for traveling in avalanche terrain implies a minimum of two variables. The first is the obvious dichotomous event variable of avalanching or an accident: either the event occurs or it does not. The second variable relates to the assessment of avalanche conditions by the decision support system itself.

As we have seen in the previous section, decision support systems can be roughly divided into two categories: knowledge based and rule based. Knowledge-based systems generally give robust results near the extremes of their operational ranges. In other words, when avalanche conditions are comparatively dangerous or comparatively safe, such systems provide quite reliable estimates of actual avalanche hazard, even when interpreted by novices. However, in the middle of their operational ranges, where avalanche conditions are ambiguous, highly variable, or dependent on one or two critical pieces of non-obvious data, knowledge-based systems can require considerable expertise to interpret. And even when interpreted by experts, knowledge-based decision systems will generally yield results that are subject to some degree of (typically unspecified) uncertainty. Because many, if not most, outings by recreationists in avalanche terrain involve decisions that fall in the middle operational range of knowledge-based systems, such systems have the potential to produce more confusion than clarity, particularly among novice users. Accordingly, the results produced by knowledge-based systems are not inherently quantitative, and for practical reasons they have been excluded from this analysis.

In practice, knowledge-based systems seem to be most useful when used in conjunction with a rule-based system that gives categorical results based on relatively simple inputs. For example, the Basic Reduction Method (Section 2.1) recommends that, for moderate levels of avalanche danger (per the current avalanche bulletin), slopes steeper than 39° should be avoided. While the exact criteria defining the categories are perhaps arguable, the results are unambiguous for specific framework thresholds: the framework either recommends travel on the slope or it does not. Such results have obvious appeal to novice recreationists who typically desire clear guidelines for decision making in the face of uncertainty, even at the cost of some (typically unspecified) predictive accuracy. Other rule-based systems investigated here (Reduction

Method, SnowCard, NivoTest, checklist sum) convert a set of situational cues into graduated categories of risk. Ultimately, however, the user is intended to interpret the system output as a recommendation to either proceed onto the slope or route (typically with certain specified precautions), or to avoid it altogether. For the purposes of the foregoing analysis, this outcome is viewed as inherently dichotomous.

3.2 Analysis of variables[3]

An analysis of rule-based decision support systems for avalanche terrain thus involves two dichotomous variables: event occurrence and system recommendation. A typical hypothesis for testing the usefulness of such a support system is that the frequency of occurrence of one variable is independent of the frequency of occurrence of the second variable. Testing such a hypothesis generally proceeds by arranging the data in a contingency table, in this case having a total of four elements (Table 5). In a typical analysis, the frequencies of the table elements are statistically compared and the hypothesis is either accepted (i.e. no useful relationship between the variables) or rejected based on the results of the comparison and confidence limits of the analysis. An important aspect of this analytical approach is that the *predictive value* of the decision system can be explicitly calculated from the observed frequencies in the contingency table. In other words, the analysis allows us to estimate how often the decision system will correctly predict an event, how often it will correctly predict no event, and how often it will be in error (false positive and false negative). Robert Bolognesi provides a brief summary of this approach in Appendix B.

A full contingency analysis requires that all four of the table elements be explicitly known. In the case of avalanches and avalanche accidents, many event instances are well-characterized since accident investigations often provide extensive data on snowpack, terrain, weather and human factors relevant to the

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[3] Our thanks to Robert Bolognesi for encouraging the inclusion of this section, which explicitly describes the analytical assumptions of our comparative analysis.

accident (see Section 3.3). Data for non-event instances, however, is problematic.

Table 5:
Conventional contingency table for two dichotomous variables

	System output	
Outcome	*Go*	*No go*
Event	False positive	True positive
Non-event	True negative	False negative

First and foremost, there is considerable uncertainty inherent in non-event avalanche data, since not triggering an avalanche does not categorically imply stability. For example, many skiers might descend a slope in the morning, but in the afternoon a single skier might trigger a fatal avalanche on the same slope. In this case, did the snowpack conditions change from stable (non-event) to unstable (event) in a few hours, or was the final skier merely the first to hit the trigger point of an unstable slab? A commonly emphasized point in avalanche courses is that the passage of other skiers does not establish the slab as stable. Another related example can be observed in popular backcountry areas in North America, where aggressive recreationists descend suspect slopes under highly unstable conditions. If these users do not trigger an avalanche, is it appropriate to classify their actions as non-event data, when a subsequent skier on the same slope might, in fact, trigger an avalanche? Such questions would need to be answered in order to meaningfully classify these cases as event or non-event data, but unfortunately such answers are beyond the current understanding of avalanche phenomena.

A second problem associated with the reliability of non-event data is related to the large number of variables that play a role in successfully navigating avalanche terrain. For example, an expert party might successfully descend a suspect slope by carefully managing variables such as micro- and macro terrain features, skier spacing, islands of vegetation, path history, and knowledge of weak layer character and depth. In contrast, a novice party might trigger an avalanche on the same slope as a result of disregarding these variables. In order to perform a robust comparison between event and non-event data, these variables would have to be controlled for (or their uncertainty quantified) in order to definitively establish the expert's route as a non-event.

A third problem associated with non-event data relates to its quality. We've seen that a robust cross-sectional contingency analysis requires that non-event data include a significant number of variables related to snowpack, weather, terrain and human factors. In general, recreational backcountry users do not routinely collect or record this type of information, but if they did, one would expect considerable variability in its quality and consistency. Some operations, such as ski resorts and commercial ski guiding services, routinely collect both event and non-event data, but it is by no means clear that the snowpack conditions under which these entities operate is representative of the avalanche conditions that a typical recreationist encounters. It seems likely that using such data in a comparison of decision methods would introduce significant biases.

Finally, we are not optimistic that a robust contingency analysis would yield very impressive predictive values for the simple decision algorithms reviewed here. Historically, considerable effort has been expended on computer-based avalanche forecasting algorithms that use increasingly more variables in increasingly complex models. To date, these efforts have produced very modest results, even in relatively well-controlled settings such as ski resorts, and they continue to fall far short of the performance of experienced human forecasters. Thus we would expect that highly simplified, rule-based frameworks for recreationists traveling in the backcountry would exhibit considerably less predictive value.

Due to the difficulties posed by the reliability of non-event data, a full contingency analysis of predictive value does not seem appropriate as a method for comparing the decision frameworks described in Section 2. Instead, we proceed by using a *preventive value* parameter, which describes the proportion of accidents that a given decision framework would have prevented. This parameter is discussed in Section 4.

3.3 Source data

The event data for this analysis came primarily from a database constructed for previous studies on decision making by avalanche victims (McCammon, 2000; 2004). The dataset was augmented for this analysis using snowpack and weather records maintained by regional avalanche forecasting centers in the United States, and with specific case information from accident investigators.[4] 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 or reconstructed from coincidental observations of snowpack and weather. In order to preserve the character of the data, no attempt was made to fill in missing information with likely or extrapolated data. While this practice resulted in lower sample sizes than would have been ideal, our intent was to assess the exact character of the data as free from personal bias or assumptions as possible.

4. PREVENTION VALUE

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.

Because this analysis relies on accident data rather than non-event 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

---

[4] While we encourage other researchers to repeat this study in with other accident data, we must point out that researching, compiling and tabulating accident data to the level of detail required in this study represented a substantial effort that represented many months of work.

accidents. Until explicit non-event data is known, the exact relationship between prevention and prediction will remain obscure.

4.1 Methods

We evaluated the prevention value 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 prevention values 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 all accidents in the study.

Snow climate where the accident occurred, following the definitions of Mock and Birkeland (2000) and Tremper (2001 p. 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.

Danger level at the time of the accident, as defined by the North American conventions for Low through Extreme avalanche danger. 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 χ^2 ($2 \times n$ 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. $p \geq 0.05$) were pooled to compute binomial confidence limits (95%) for the finite population of accidents where the proportion applied.

4.2 Results

Accident records provided enough information to compare prevention value across almost all categories. Table 6 summarizes the results.

NivoTest – 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 most aggressive NivoTest guidelines, 65±8% of the 115 accidents would have been prevented. The minimum NT score in this data set was 14, somewhat higher than the lower limit of 8 proposed for Europe. The maximum NT score was 36. A linear regression for the relationship between NT score and prevention value yields:

$$X = -0.045(NT) + 1.632; \;\; r^2 = 0.9926 \qquad (2)$$

where X is the proportion of accidents prevented, NT is the NivotTest score, and r^2 is the coefficient of determination. NivoTest scores corresponding to a specific number of accidents prevented can be calculated by rearranging Equation 2 or by inspection from Figure 4.

The NivoTest, like all of the other frameworks, 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 Nivotest showed significant sensitivity to snow climate, where prevention values ranged from 54±13% for intermountain ranges to 79±16% for maritime

Table 6:
Statistical results from threshold comparison of the five decision frameworks

	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	-		-		-	
Danger Rating			**<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	-		-	
Danger Rating			**<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	

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 χ^2 probability of the proportions being the same. Where $P < 0.05$, the categories have significantly different accident proportions and where $P \geq 0.05$, the category proportions are not significantly different from all accidents of known score (top row).

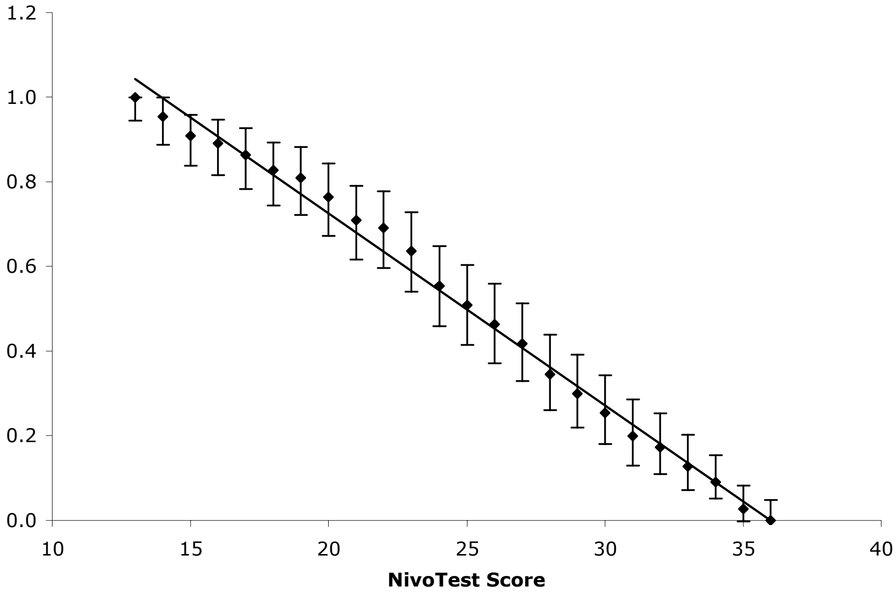

Figure 4. Plot of NivoTest score versus the proportion of historical accidents prevented. The trendline represents the linear regression of Equation 2

ranges. The method would have prevented no accidents at low danger levels, and a generally increasing proportion as the danger level increased.

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

Reduction Method – 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

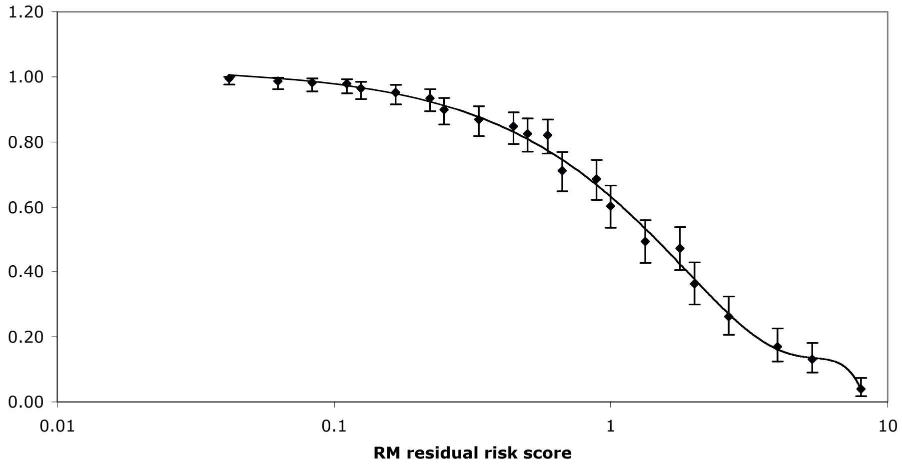

Figure 5. Plot of Reduction Method scores versus the proportion of historical accidents prevented. The trendline represents the polynomial regression of Equation 3.

less conservative threshold of 2.0 would have prevented only 36±6% of accidents. Figure 5 illustrates the relationship between RM score and prevention value. The recommended threshold value of 1.0 would have prevented 60±5% of accidents, a finding that differs somewhat from Munter's estimate of 75% for the Swiss Alps (Munter, 2003a). The overall relationship between residual risk and prevention value is shown in Figure 5; a stepwise polynomial regression indicates that a third-order relationship is a statistically significant fit to the data:

$$X = -5.123\exp(-3)(RR^3) + 8.463\exp(-2)(RR^2) - 0.472(RR) + 1.025; \;\; r^2 = 0.9952 \quad (3)$$

where X is the proportion of accidents prevented, RR is the residual risk given by the Reduction Method framework (Equation 1), and r^2 is the coefficient of determination.

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 proportions of accidents prevented in intermountain/transitional and continental climates (hence their data were pooled at each threshold level). The RM was significantly more conservative in maritime climates. As with the other methods, the proportion of accidents prevented rose with the danger level.

SnowCard – We evaluated the SnowCard 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 thresholds suggested by SnowCard designers, orange and yellow, would have prevented 75±4% and 86±4% of accidents respectively. Prevention values for other thresholds on the SnowCard are shown in Table 7. The SnowCard was statistically insensitive to victim training, activity and slab type, and showed only marginal sensitivity ($0.5 \leq P < 0.1$) to snow climate. As in the other methods, prevention value generally increased with increasing avalanche danger.

Table 7:
Prevention values for SnowCard thresholds

Threshold	*Prevention value*	*n*
Green	94±3%	16
Lime	91±4%	8
Yellow	86±4%	11
Orange	75±5%	29
Red	0%	193

The threshold refers to the upper limit of the SnowCard color indicated. The variable *n* is the sample size.

Checklist Sum – The method based on the checklist sum, or 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 prevention value of this method drops significantly above 4 clues (Table 8), thresholds of 5 clues or more 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 snow climate. As in the other methods, prevention value generally increased with increasing avalanche danger.

Table 8:
Prevention values for checklist sum thresholds.

Threshold	*Prevention value*	*n*
0	100%	0
1	100%	1
2	98±2%	4
3	92±3%	14
4	77±5%	39
5	47±6%	76
6	10±4%	93
7	0%	25

The threshold refers to the number of clues present (Table 4). The variable *n* is the sample size.

4.3 Discussion

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 the potential for significant accident prevention.

Training – Prevention value did not vary significantly with the training level of the accident party. This result suggests that conditions that kill avalanche novices are very similar to the conditions that kill more highly trained individuals, a finding that replicates earlier studies McCammon (2000; 2004). While this result implies that formal decision frameworks have the potential to significantly reduce the number of accidents, it also underscores the importance of ensuring that such systems are not only easy to use but permit a degree of mobility that makes them attractive to more experienced users.

Activity – There were no statistically significant differences in prevention values across the various activity types. These results do not support the hypothesis that these frameworks might perform differently for skiers than for snowmobilers in the U.S.

Climate – Prevention values showed significant variation by snow climate across almost all the methods evaluated. In general, the methods performed more conservatively, i.e. prevented more accidents, in maritime climates than in intermountain or continental climates. For some frameworks these differences were substantial. Only the SnowCard and the checklist sum method (threshold 3) showed no significant sensitivity to snow 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 robustly evaluated in this respect due to small sample sizes.

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

5. 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 are likely to be eventually disregarded. Mobility, or the range of terrain accessible under each framework threshold, is thus of critical importance to the overall utility of these methods.

5.1 Methods

In theory, there are many ways to quantify the amount of mobility that is afforded under a given decision framework. Geyer (2001) considers the total number of trips that would be possible under a specific decision framework. Using trip data of the DAV Summit Club (the guiding branch of the German Alpine Club), he reports that out of a total of 1705 trips scheduled for the 2000/01 season, 151 were cancelled due to avalanche conditions. Of those trips cancelled, 17 were cancelled due to violations of the Reduction Method or the Limits Method (a simplified version of the Reduction Method). Thus the two decision frameworks permitted about 99% of the trips to take place. Bolognesi (Appendix B) suggests a definition of mobility that is also tied to non-event data. Both approaches have merit, but suffer from the fundamental uncertainties inherent in non-event avalanche data (described in Section 3).

The measure of mobility used here 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 danger level, we compared slope angle maximums only within each level of danger. And because most frameworks do not perform well at low danger levels or apply at extreme danger, we considered mobility measures only in those accidents that occurred during periods of moderate, considerable and high avalanche danger (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-danger curve (Figure 6) as a proportion of the area under the 50° curve

$$Ms_k = \left(\frac{A_{1k} + A_{2k}}{2A_{50}} \right) \times 10 = \frac{b_k + c_k + 0.5(a_k - c_k)}{10} \tag{4}$$

where *a*, *b* and *c* are the maximum effective slope angles at each danger level for the k^{th} framework threshold. The result is scaled to a maximum value of 10 for inclusion in the utility function described in a later section.

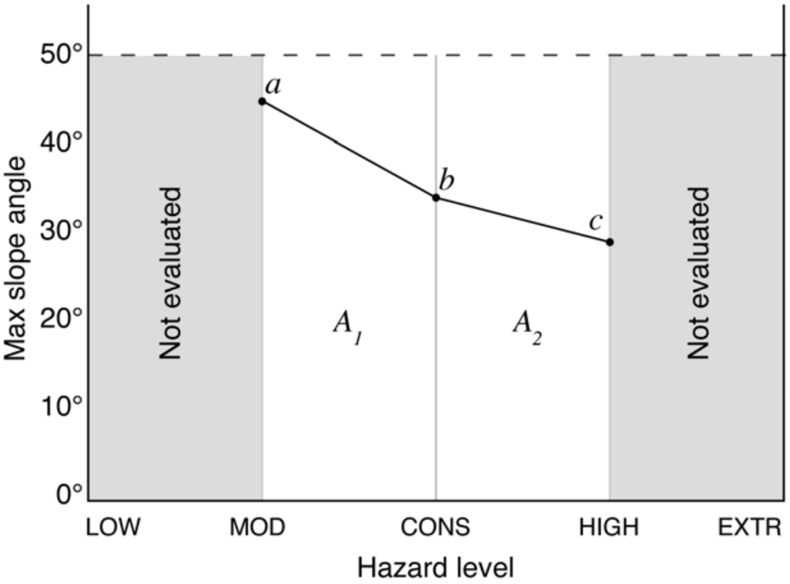

Figure 6: Slope-angle mobility for each framework was calculated as the area under the slope angle – danger curve (A1 + A2). Variables a, b and c represent the maximum slope angle permitted under the framework threshold, either specified by the framework or determined from accident data.

In the Basic Reduction Method (M, C, H danger levels), the Reduction Method and SnowCard (C and H danger), maximum slope angles are explicitly defined; these angles were used directly to calculate slope-angle mobilities (Table 9). 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 < 0.0001 to 0.54), we used the nonparametric Kruskal-Wallis test (or *H*-test) to assess differences.

5.2 Results & Discussion

Slope angle mobilities are shown in Table 9. Mobilities range from a maximum of 8.3 (NT, OC) to a low of 6.8 (BRM). 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 dangers, and thus ranks lower than the NivoTest, or checklist sum methods, which do not categorically prevent travel on steep slopes.

Table 9:
Slope-angle mobilities (M_S) of framework thresholds.

	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	

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 a measure of absolute mobility, M_S is a admittedly a low-resolution metric. It delineates general differences between methods but does not (due to small sample size for slope angle maxima) substantively distinguish between different threshold values of the same framework (e.g. RM, OC). Nevertheless, it provides a general measure of relative mobility that, in lieu of more detailed measures, permits meaningful comparisons between methods.

6. MITIGATION

All of the decision frameworks in this study were intended by their designers to be used in conjunction with standard “safe travel” practices for avalanche terrain. Such practices include: 1) ensuring that all members of the party are wearing avalanche beacons and carrying avalanche rescue equipment, 2) exposing only one person at a time on suspect slopes, 3) utilizing safe positioning of the party in hazardous terrain, and 4) not traveling alone. While some of the methods, most notably the RM and NT, incorporate these practices into their numerical risk reduction estimates, other methods treat these practices as supplemental safety measures. In this section, we review the impact that some of these measures have on the preventive value of the various decision frameworks.

6.1 Methods

Our data set included fairly robust information about beacon use among accident parties. Also, exposure of multiple party members could reliably be inferred from the number of party members caught or buried in the accident. Other mitigation measures, such as traveling alone and the use of safe positioning by the party, were subject to reporting biases and thus were not included in the analysis.

We computed the proportion of accidents prevented by any (*k*) framework as

$$P_k = \frac{n_{f,k} + n_m}{N} = P_{f,k} + \left(1 - P_{f,k}\right) \prod_i P_{m,i} \tag{4}$$

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 side of the 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.

6.2 Results and discussion

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 apparently improved the survival chances of fully buried victims by about 14.1%, which is equivalent to 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 older analog beacons used during the period of 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 7 summarizes the cumulative prevention value 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 6.

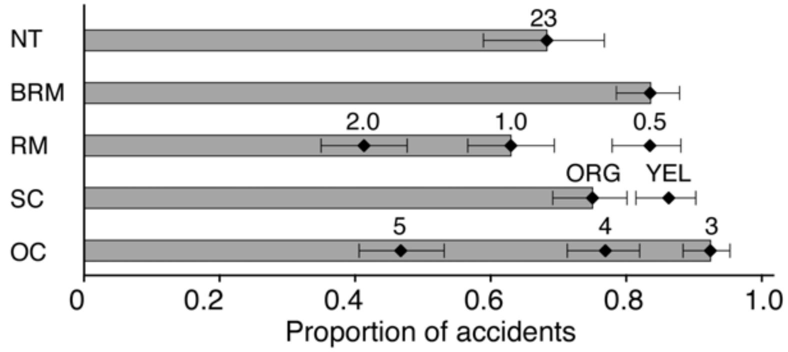

Figure 7: Proportion of accidents prevented by each framework if victims had worn beacons and exposed one person at a time. Customary thresholds are shown by the shaded bar; other thresholds shown for comparison. Error bars indicate the 95% binomial confidence limit around the data proportion (◆) for each threshold value.

7. EASE OF USE AND UTILITY

Even if a decision framework has a high prevention value and provides for considerable 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 preferences and the sensory-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 the 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 chose a 10-level ranking system where the most preferred framework has the largest rank value.

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

The answer to this question 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 their optimal choice using a utility function that quantifies the user's overall satisfaction with a particular framework (Baron, 1994)

$$U_k = \sum_i w_i r_{k,i} = w_1 P'_k + w_2 Ms_k + w_3 E_k \ , \qquad (5)$$

where P'_k is the prevention value of the k^{th} framework adjusted to a 10-level comparison scale ($P_k \times 10$), M_{sk} 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 prevention value, 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.

Every user will have a unique set of preferences and requirements regarding prevention value, 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 (5). 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 8. Rank frequencies converged to within 2% of their final values after 3000 iterations. As shown in Figure 8, the optimality frequency of threshold of 3 in the checklist sum method based on obvious clues is striking at 42%. When threshold values of 3 and 4 are combined, the checklist sum method is optimal 54% of the time. A similar pattern appeared in the median rankings of the methods across all simulation cases.

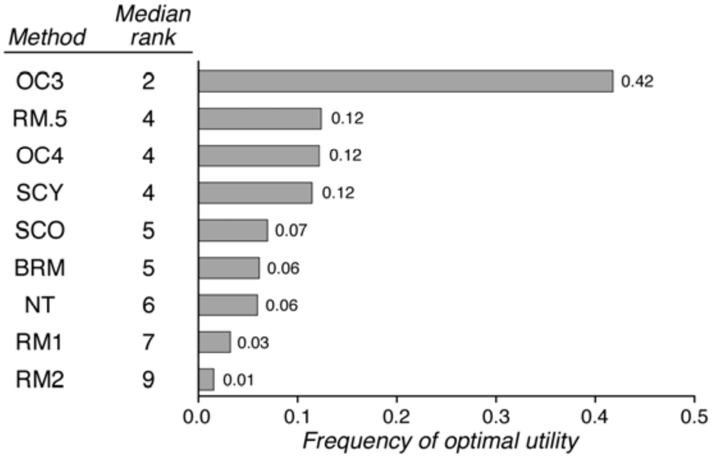

Figure 8: Frequency of optimal utility of the various frameworks evaluated across 3000 random sets of preferences. Decisions based on a checklist sum of 3 (Table 4) are most frequently optimal.

Despite incorporating a rather coarse approximation of mobility, the simulation results of optimal utility 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 prevention value, mobility and ease of use.

8. 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. While the authors recognize that there are inherent limitations to any analysis based on historic data, we believe that the present study has value as a preliminary investigation of the differences between avalanche decision frameworks.

The analysis focused on three aspects of decision frameworks: prevention, mobility and ease of use. Clearly, these are not the only factors across which different decision frameworks might be compared. Other factors, such the educational value of the frameworks, or the ability of methods to deal with missing or incomplete data, were not examined in this study.

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. In contrast, most of the methods showed significant sensitivity to snow 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 checklist sum method), customary thresholds of the frameworks were ineffective at preventing accidents during periods of low or moderate danger, 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 admittedly coarse approximation based on the maximum slope angle permitted by the framework at the danger levels where frameworks were most likely to be used by recreationists (moderate through high danger). 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 danger) 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 of personal preference, and is influenced greatly by the sensory-cognitive 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 ease of use among the various decision frameworks.

Utility – For any given user, the overall utility of any framework is a combination of its prevention value, 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 the checklist sum 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 4) to potential avalanche slopes represented the most effective rule-based decision strategy for avalanche terrain, based on accident data from the U.S. While the exact definitions of the 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.

The majority of avalanche accidents in this study 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 identify fairly obvious conditions in a formal but simple way. One of the key questions remaining relates to why even well-trained recreationists become avalanche victims under conditions that should be easily recognizable. Recent research is increasingly emphasizing the importance of addressing human factors in avalanche accidents (e.g., McClung, 2002; McCammon, 2004; Adams, 2005). It appears likely that simple decision aids, such as the existing decision frameworks reviewed in this report, act to minimize some of these factors by providing very simple and objective decision criteria.

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APPENDIX A:

EVALUATION OF DECISION SUPPORT SCHEMES WITH RESPECT TO 3-BY-3 FRAMEWORK

In this appendix, the different methods are examined with respect to the 3-by-3 Formula (Munter, 1992; 1999, 2003a), a well-established framework for decision-making in avalanche terrain.

The analysis points out the data needs and the required skills for the different support schemes.

- A1: Reduction Method (Munter)
- A2: Stop-or-Go (Larcher)
- A3: SnowCard and FaktorenCheck (Engler)
- A4: NivoTest (Bolognesi)

A.1 Reduction Method (Munter)

	Weather & Snow	Terrain	Human
regional	• Danger rating (PAB, RP) • Usage freq. of trip (RF$_2$)	• Max. incl. on map (RF$_1$) • Terrain info (PAB) • Aspect on map (RF$_2$) • Elevation on map (RF$_2$)	• Group size (RF$_3$)
local	• Danger rating (PAB, RP) • Usage freq. of route (RF$_2$)	• Max. incl. in terrain (RF$_1$) • Terrain info (PAB) • Aspect in terrain (RF$_2$) • Elevation in terrain (RF$_2$)	• Group size (RF$_3$) • Spacing (RF$_3$)
slope	• Danger rating (PAB, RP) • Usage freq. of slope (RF$_2$)	• Max. incline (RF$_1$) • Terrain info (PAB) • Aspect (RF$_2$) • Elevation (RF$_2$)	• Group size (RF$_3$) • Spacing (RF$_3$)

dark red: Elementary Reduction Method
red: Regular Reduction Method

PAB: public avalanche bulletin
RP: risk potential
RF: reduction factor (class 1, 2 or 3)

The Reduction Method is suggested as a control instrument at all trip stages and directly/quantitatively includes factors from all three contributing aspects.

Necessary information sources:

- *Public avalanche bulletin*
  - danger rating (worst case)
  - unfavorable aspects and elevation ranges
- *Maps*
  - incline
  - aspect
  - elevation
- *Guidebooks*
  - usage frequency of trip

Necessary field skills (ranked):

1. *Estimation incline* (Elementary Reduction Method)
2. *Determination aspect and elevation* (Regular Reduction Method)
3. *Determination usage frequency* (Regular Reduction Method)
4. *Group management* (Regular Reduction Method)

A.2 Stop-or-Go (Larcher)

	Weather & Snow	Terrain	Human
regional	• Danger rating (PAB)	• Max. incl. on map	
local	• Danger rating (PAB) • New snow • Drift snow • Recent avalanche activity • Water saturation • Settlements	• Max. incl. in terrain	
slope	• Danger rating (PAB) • New snow • Drift snow • Recent avalanche activity • Water saturation • Settlements	• Max. incline	

dark red: Check 1
red: Check 2

PAB: public avalanche bulletin

The Stop-or-Go card is suggested as a decision-making instrument at all trip stages. In addition to the two checks the method also recommends well-known standard procedures for the different stages of a backcountry trip.

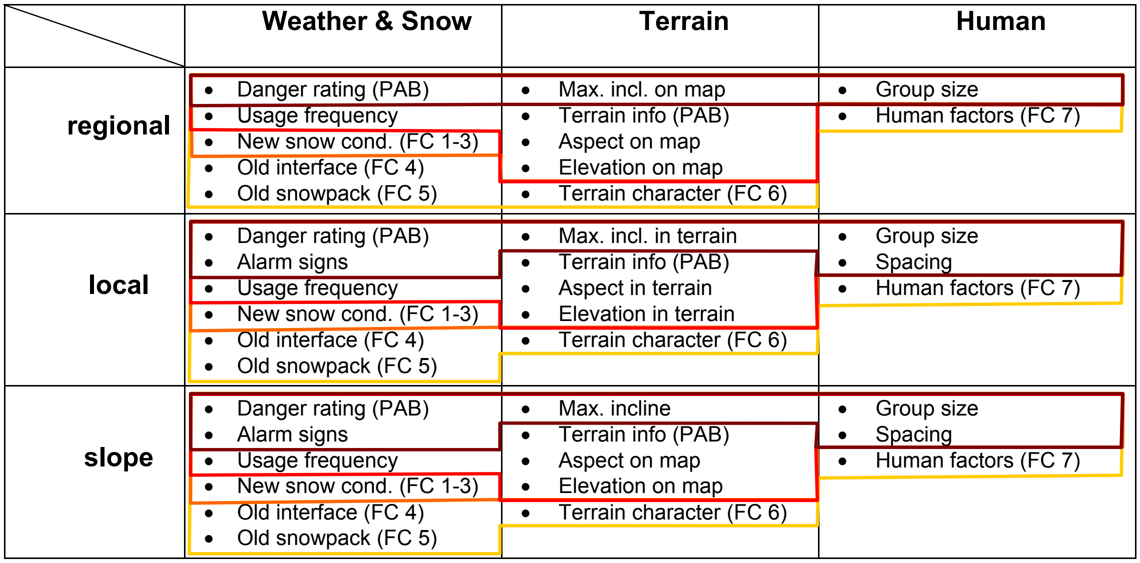
Necessary information sources:

- *Public avalanche bulletin*
  - danger rating (worst case)
- *Maps*
  - incline

Necessary field skills (ranked):

1. *Estimation incline* (Check 1)
2. *Observation and interpretation of snowfall* (Check 2)
3. *Observation and interpretation of drift snow* (Check 2)
4. *Observation and interpretation of recent avalanche activity* (Check 2)
5. *Observation and interpretation of water saturation* (Check 2)
6. *Observation and interpretation of settlement signs* (Check 2)

A.3 SnowCard and Faktorencheck (Engler)



	Weather & Snow	Terrain	Human
regional	• Danger rating (PAB) • Usage frequency • New snow cond. (FC 1-3) • Old interface (FC 4) • Old snowpack (FC 5)	• Max. incl. on map • Terrain info (PAB) • Aspect on map • Elevation on map • Terrain character (FC 6)	• Group size • Human factors (FC 7)
local	• Danger rating (PAB) • Alarm signs • Usage frequency • New snow cond. (FC 1-3) • Old interface (FC 4) • Old snowpack (FC 5)	• Max. incl. in terrain • Terrain info (PAB) • Aspect in terrain • Elevation in terrain • Terrain character (FC 6)	• Group size • Spacing • Human factors (FC 7)
slope	• Danger rating (PAB) • Alarm signs • Usage frequency • New snow cond. (FC 1-3) • Old interface (FC 4) • Old snowpack (FC 5)	• Max. incline • Terrain info (PAB) • Aspect on map • Elevation on map • Terrain character (FC 6)	• Group size • Spacing • Human factors (FC 7)

dark red: A-1 (mimimal)
red: A-2 (basic)
orange: B (advanced)
yellow: C (expert)

PAB: public avalanche bulletin
FC: Faktorencheck questions

The SnowCard and Faktorencheck are suggested as a decision-making tool at all stages of the 3-by-3 Formula. The Faktorencheck allows the local verification of the bulletin by the advanced (new snow situation) and expert user (comprehensive evaluation).

Necessary information sources:

- *Public avalanche bulletin*
  - danger rating (A-1)
  - unfavorable aspects, elevation ranges and terrain features (A-2)
  - additional information about conditions (B)
- *Maps*
  - incline (A-1)
  - aspect (A-2)
  - elevation (A-2)
- *Guidebooks*
  - usage frequency of trip (A-2)

Necessary skills (ranked):

1. *Estimation incline in field* (A-1)
2. *Group management* (A-1)
3. *Determination aspect and elevation and recognize terrain features* (A-2)
4. *Determination usage frequency* (A-2)
5. *Examination new snow situation* (B)
6. *Inspection old snow conditions* (C)
7. *Detailed terrain analysis* (C)
8. *Incorporation human factors into decision-making process* (C)

A.4 Nivotest (Bolognesi)

Backcountry travelers should reconsider their trip plans when any of the following conditions appear:

<table>
<tr><th></th><th>Weather & Snow</th><th>Terrain</th><th>Human</th></tr>
<tr><td>regional</td><td colspan="3">• Avalanche danger rating (PAB) considerable and inexperienced group
• Avalanche danger rating (PAB) high
• Existing or approaching severe weather conditions
• Tired, sick or injured group members
• Defect or missing equipment (e.g., beacon, shovel, probe)</td></tr>
<tr><td>local</td><td colspan="3">• Nivotest result: ☹
• Local alerts (e.g., closed areas in resorts)
• Warning by local professional (e.g., ski patroller, guide)
• Group is running out of time</td></tr>
<tr><td>slope</td><td colspan="3">• Indicators for potential avalanche danger (snow accumulation, cracks, etc.)
• Alarm signs (settlements, remotely triggered avalanches, etc)</td></tr>
</table>

dark red: Nivotest

PAB: public avalanche bulletin

(Bolognesi, 2003)

In addition to the three different possible test outcomes (☺, 😐, ☹), the Nivotest also suggest standard practices that should be followed under any conditions.

Necessary information sources:

- *Public avalanche bulletin*
  - danger rating

Necessary field skills (ranked):

1. *Answering 25 yes-no questions regarding*
   - weather conditions
   - snow conditions
   - recent avalanche activity
   - terrain characteristics of intended route
   - condition and equipment of participants.

APPENDIX B:
RESPONSES FROM DEVELOPERS AND PRACTITIONERS

We would like to thank the following individuals for sharing their ideas about rule-based decision-making frameworks and giving us feedback on earlier drafts of this report. Comments that were not addressed explicitly in the text or that were extensive are reprinted in this appendix (marked by an asterisk). In the following appendix, we respond to comments by reviewers.

- *Laura Adams: Geospatial Research Centre, Selkirk College
- Colani Bezzola: Canadian Mountain Holidays (CMH)
- *Robert Bolognesi: Meteorisk, Developer of NivoTest
- Martin Engler: Developer of SnowCard and Faktoren Check
- Stephan Harvey: Swiss Federal Institute for Snow and Avalanche Research (SLF)
- Bruce Jamieson: University of Calgary (UoC)
- Michael Larcher: Developer of Stop-or-Go
- Werner Munter: Swiss Federal Institute for Snow and Avalanche Research (SLF), Developer of Reduction Method
- *Howie Schwartz: American Institute for Avalanche Research and Education (AIARE)
- Jürg Schweizer: Swiss Federal Institute for Snow and Avalanche Research (SLF)
- Francois Sivardière: Association national pour l'étude de la neige et des avalanche (ANENA)

B.1 Comments from Latura Adams

REVIEW
of the
Canadian Avalanche Association's

DESCRIPTION AND EVALUATION
OF
EXISTING EUROPEAN DECISION-MAKING SUPPORT SCHEMES
FOR RECREATIONAL BACKCOUNRY TRAVELERS

Prepared by Laura Adams, November 9, 2004
Selkirk College and the Selkirk Geospatial Research Centre

General Comments

This manuscript provides a comprehensive review of the existing European decision support schemes including a valuable comparison of the methods within the context of their application in North America. The authors provide a detailed and descriptive perspective of current approaches to recreational avalanche decision support and utilized a strong statistical comparison of methods in their analysis. This synthesis offers an informed foundation upon which to consider the design and implementation of a decision support system (DSS) for winter recreationists in North America. In addition, the work is an excellent contribution to the knowledge of decision support schemas in the avalanche domain, since little literature was previously available on the subject, particularly in English.

Specific Comments

1. The methodology applies European decision-making schemes to an American data set of avalanche accidents. I suggest local calibration is important to validate the findings if these frameworks may be considered for use in Canada. I assume the authors did not use a Canadian data set if it did not meet the criteria of being statistically robust. However this appears to be an important

consideration, especially in light of their findings of a significant sensitivity to snow climate.

2. The social, cultural and environmental differences between Europe and North America have not been identified and discussed in this review, however I suggest they should be an important consideration in determining the potential application of both the findings and the methods for use in North America.

3. The authors have identified the critically important point that a North American recreational decision support system (DSS) must be easy to use and appeal to the sensory-cognitive orientations of the user. This is very important consideration in the future design and implementation of a DSS system. These systems are necessary since novices face significant limitations in avalanche-related decision-making and lack the experientially created knowledge to perform skills and cognitive processes at the knowledge-based level. Effective DSS must be designed to naturally integrate with the needs of the user, and we cannot expect the user to adapt to the needs of the system.

Decision support systems are most effective when they are designed with an understanding of the cognitive skills, fundamental knowledge, and strategies that are necessary for proficient performance. Strategies to support decision practice and build decision skills can then be designed to enhance the natural processes occurring in human decision-making. The avalanche domain lacks research that directly addresses this issue, and it is generally difficult to measure the value of an intervention when there is a lack of longitudinal data available.

4. The concluding comment that "decision frameworks need only to identify fairly obvious conditions" does not consider the role of human factors in avalanche accidents. While this perspective addresses the environmental conditions present in a majority of the avalanche accidents in the study, it does not address the complexity of human factors and the fact that their presence and role in avalanche accidents has not been adequately captured in the empirical data. While it is important to capture the human role in the task of avalanche-related decision-making within a small set of rules, we must ensure that we don't eliminate the role of humans in the process.

Comments Specific to the Research and the Project Goals

While this manuscript represents a current perspective on European approaches, it is important to consider several limitations inherent in the avalanche domain. These summary comments are provided with the goal of encouraging a social sciences perspective to be considered in regards to the overall project goal that aims to develop a decision support framework for amateur winter recreationists in North America. These limitations include the lack of human science research and how risk is conceptualized in the avalanche domain.

Avalanche researchers and practitioners recognize the significant role that human factors play in avalanche accidents, however, there is very little published literature that examines the human component of avalanche phenomena, consequently our understanding of this topic is weak. Designing and incorporating a human risk factor into a North American recreational DSS would be a significant advancement to the methods reviewed in this manuscript. However, the ability to integrate human factors into a DSS is complicated by the fact that the avalanche domain lacks human science research, and that North America lacks empirical and longitudinal data of human factors in avalanche accidents.

The decision schemes reviewed in this manuscript indicate this lack of knowledge, since the emphasis is weighted more heavily upon the physical properties of the terrain and snowpack while the human component is reduced to several factors that are quantifiable - primarily training, safety equipment, group size and spacing. As a result, the human component of avalanche-decision making is not comprehensively incorporated into the systems evaluated in this study, therefore a holistic approach to DSS is not achieved. I suggest that defining human factors, clearly identifying their characteristics, and recording their appearance in avalanche accidents is critical for future research and the effective design of DSS such as this one undertaken by the CAA.

A key component in DSS is risk assessment, and I suggest we need to rethink how risk is viewed in the avalanche domain. The current definition of risk used in the avalanche domain is one of a physical sciences perspective. However risk, as viewed by social scientists, is a social construct that is invented to help us cope and understand the dangers and uncertainties of life. This perspective argues that risk is inherently subjective, and that it does not exist externally, waiting to be measured.

Risk assessment from a social sciences perspective represents a blending of science and judgment with important psychological, social, cultural, and political factors. It is critically important to understand how risk is perceived and evaluated by recreationists in order to design effective strategies for avalanche risk management. We currently lack this understanding in the avalanche domain.

B.2 Comments from Robert Bolognesi

Description and evaluation of existing European decision-making support schemes for recreational backcountry travelers.

Response from Robert Bolognesi, Ph. D., designer of NivoTest,
to the paper prepared by Ian McCammon, Ph. D, and Pascal Hägeli, Ph. D.

November 2004

Thanks to the authors for giving the opportunity to express an opinion about their study.

1. Some minor remarks

Page 1 : The NivoTest was not introduced in 2000 but in 1999 (1st presentation in March 1999 and then during the X-TREM free-ride contest in Verbier).

Page 16 : The NivoTest is used in France, in Italy, in Spain and in the French part of Switzerland. It is supported by the French Alpine Club, by the State Rescue Organization OCVS, by the Ski Patrolmen Association of the French and Italian parts of Switzerland and by the Italian Alpine Club. It is distributed by the French National Association for Snow and Avalanche Studies (ANENA) with the agreement of its affiliates : Météo-France, CEMAGREF, French Mountain Guides Association, French Ski Instructors Association, Safety Services Chiefs Association, etc.

2. Some major remarks

A. About evaluation criteria

Using 3 parameters (prevention value, mobility and ease of use) to assess the helpfulness of the frameworks is good but not enough. One should consider some other important parameters too :

- **Educational value** : a framework should be a decision support tool but also a mean to learn (and teach).
- **Stability** : the outputs of a framework should not differ a lot when one input differs slightly.
- **Ability of using uncertain or partial information ;** a framework should stay usable even if some inputs are missing (that is possible if the framework consists of many inputs).
- **Ability of being operative without the avalanche bulletin ;**
  This point is very important because :
  - the avalanche bulletin is not always available : no bulletin in distant countries, no bulletin in summer or autumn (20% to 30% of the avalanche fatalities in Europe happen during these periods of the year),
  - the avalanche bulletin may be correct at the regional scale but incorrect at the local scale because of specific local conditions ;

B. About sample and methods

Some points are very controversial !

- **Composition of the sample**
  The sample should not include all the reviewed accidents but should be composed in order to reflect the statistical distribution of the various kinds of snow situations as well as the ratio "number of accident / number of ski excursions", otherwise the results of the evaluations is biased.

- **Evaluation of prevention value and mobility**
  One have to consider the whole information contained in a contingency table (following figure)

		Output of the framework	
		Stop	Go
Occurrence of an accident	No	a	b
	Yes	c	d

(a, b ,c ,d : number of reviewed cases)

The study only considers the quotient $c/(c+d)$ showing the proportion of accidents which would have been prevented, but does not take into account some other significant quotients :

- the quotient $(b+d)/(a+b+c+d)$ which measures the mobility better than an evaluation of maximum slope angles
- the quotient $(\alpha c+\beta b)/(a+\beta b+\alpha c+d)$ which indicates the global effectiveness of the framework (α and β are weighting factors).

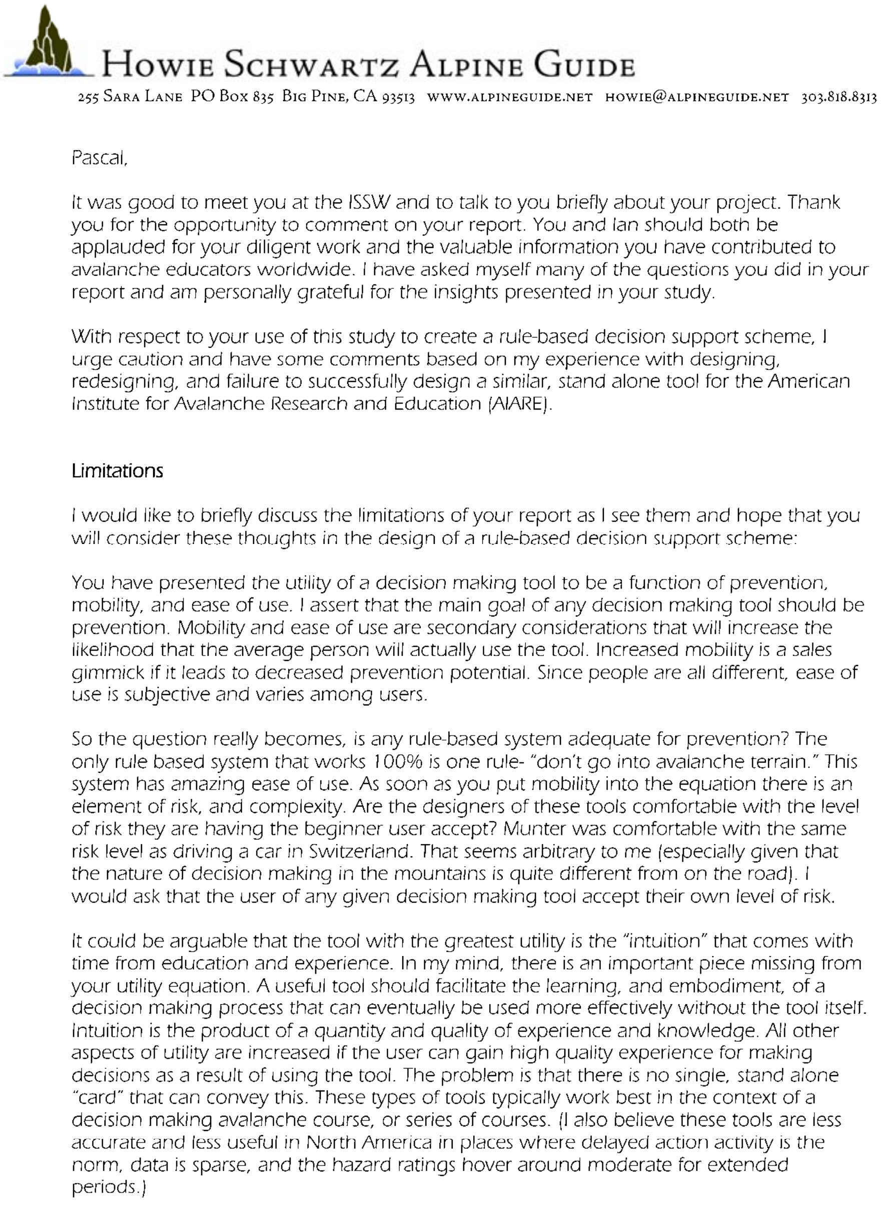
- **Evaluation of NivoTest**
  The NivoTest is not a "Go/No-go" framework, because it is not reasonable to give a same answer to different users. One can say "Stop" to a beginner and at the same time "Go" to an experienced mountaineer. Consequently, the evaluation of the utility of the NivoTest should distinguish the type of user (beginner, experienced backcountry traveler, professional).

- **Evaluation of utility**
  The utility function combines doubtful results concerning prevention value and mobility : can we trust it ?

3. In short…

- Presentation of frameworks : very good
- Sample, criteria and methods : debatable
- Sort of the frameworks : uncertain
- NivoTest : many advantages were not considered in the study. It is a pity…
- ChekList Sum : surely an efficient framework (perhaps better without clue "Rating")

B.3 Comments from Howie Schwartz



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Pascal,

It was good to meet you at the ISSW and to talk to you briefly about your project. Thank you for the opportunity to comment on your report. You and Ian should both be applauded for your diligent work and the valuable information you have contributed to avalanche educators worldwide. I have asked myself many of the questions you did in your report and am personally grateful for the insights presented in your study.

With respect to your use of this study to create a rule-based decision support scheme, I urge caution and have some comments based on my experience with designing, redesigning, and failure to successfully design a similar, stand alone tool for the American Institute for Avalanche Research and Education (AIARE).

Limitations

I would like to briefly discuss the limitations of your report as I see them and hope that you will consider these thoughts in the design of a rule-based decision support scheme:

You have presented the utility of a decision making tool to be a function of prevention, mobility, and ease of use. I assert that the main goal of any decision making tool should be prevention. Mobility and ease of use are secondary considerations that will increase the likelihood that the average person will actually use the tool. Increased mobility is a sales gimmick if it leads to decreased prevention potential. Since people are all different, ease of use is subjective and varies among users.

So the question really becomes, is any rule-based system adequate for prevention? The only rule based system that works 100% is one rule- "don't go into avalanche terrain." This system has amazing ease of use. As soon as you put mobility into the equation there is an element of risk, and complexity. Are the designers of these tools comfortable with the level of risk they are having the beginner user accept? Munter was comfortable with the same risk level as driving a car in Switzerland. That seems arbitrary to me (especially given that the nature of decision making in the mountains is quite different from on the road). I would ask that the user of any given decision making tool accept their own level of risk.

It could be arguable that the tool with the greatest utility is the "intuition" that comes with time from education and experience. In my mind, there is an important piece missing from your utility equation. A useful tool should facilitate the learning, and embodiment, of a decision making process that can eventually be used more effectively without the tool itself. Intuition is the product of a quantity and quality of experience and knowledge. All other aspects of utility are increased if the user can gain high quality experience for making decisions as a result of using the tool. The problem is that there is no single, stand alone "card" that can convey this. These types of tools typically work best in the context of a decision making avalanche course, or series of courses. (I also believe these tools are less accurate and less useful in North America in places where delayed action activity is the norm, data is sparse, and the hazard ratings hover around moderate for extended periods.)

Good decisions, at any experience level, are those that make the best possible use of terrain. We teach courses based on the premise that decision making equals terrain selection, plus travel techniques. The schemes you analyzed in your study are significantly decreased in utility by their design because they don't assist the user to evaluate their specific terrain beyond general ranges of incline. They cannot give many useful travel techniques because they do not evaluate specific terrain for the user. These schemes also do not address the human factors that lead to poor terrain selection. The danger of these tools, if used alone, is that they don't enable the user to appropriately assess risk, the terrain, the group, or to strategize risk mitigating travel techniques, before decisions are made. Laura Adams' (Selkirk Geospatial Research Centre) paper on Supporting Sound Decisions supports the concept that it is human factors and terrain selection that are most valuable for prevention, over the factors that are analyzed using rule-based schemes. I believe this to be true even if not yet accepted as science.

A major flaw of the decision making tools you evaluated (including the 3x3) is that they are based in the popular go/ no go paradigm. To go or not to go (see my ISSW poster presentation/abstract) is rarely the question. Rather, it is: where to go, or terrain selection. This is an important distinction because when a person is faced suddenly with an "all or none" decision, human factors tend to make it- especially when the rule-based tools present ambiguity. This is more often the case than not in Continental snow climates in mid-winter, for example. In addition, go/no go decision making schemes suggest that important decisions should be made "locally" or "on the slope" just before a point of risk. Go/no go decision points in moderate hazard are where human factors are amplified and all decision making tools become too cumbersome. Tools meant for use at these go/no go points de-emphasize the importance of creating options in the planning stage that help to minimize the commitment factor of a given tour. There are many circumstances where we should be avoiding the use of stand alone, rule-based tools that give basic go/ no go guidance.

That said, I think there is a place for these tools. I would like to see a rule-based tool that is devised as a secondary tool- for use after terrain selection decisions are made and before actions are carried out. I can imagine value in this for students in the context of both level 1 and level 2 avalanche courses that focus on terrain selection. A rule-based scheme or checklist could be used to great effect as a component of a decision making process. This is how our courses are currently designed. As a stand alone tool that is primary for decision making though, I have doubts that an adequate rule-based scheme can be devised.

Other technical notes

Mobility:

A measure of mobility should go far beyond the incline of the terrain. There are many other terrain factors that should be evaluated. Much greater mobility is gained from a more complete terrain assessment. This is what we should be focusing on teaching recreationalists. That mobility was linked only to incline is a limitation of your study.

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Mitigation:

Mitigation measures need not be included in a rule-based decision making tool. I contend that there are not, and should not be, hard and fast rules governing travel techniques. Travel techniques can be good ways to minimize risk in avalanche terrain and are best selected and used on a case by case basis for recreational travelers. Traveling one at a time, for example, in certain terrain and conditions is a bad idea. This should not be a rule. Carrying beacons, shovels, probes, avalungs, etc. does not affect the probability of avalanche burial. They should not be included in such a rule-based tool.

Data:

You acknowledge in your report that you have analyzed data from CAIC known accidents not from usage data. Although, the data you analyzed presents valuable insights, usage data is a large missing piece. Nobody knows how many poor decisions that didn't lead to avalanche accidents were made and could have been prevented as a result of these tools. There is also no data available about the actual prevention, or failure to prevent, of these tools in the field. I mention these points because when you apply these decision making tools to past case histories, you eliminate the human factors that influenced the decision, and the specific terrain factors (other than slope angle) that may have contributed. It is virtually impossible to analyze all of these factors from the historical records, but I wonder how many of these accidents could have been prevented with seven simple human factor oriented rules, for example?

Thank you again for your contribution to avalanche education and for accepting my comments for your project. Best of luck, and please consider me a resource at your disposal.

All the best,

Howie Schwartz

AIARE Educational Committee Member
UIAGM Mountain Guide

APPENDIX C:
REJOINDER TO DEVELOPER AND REVIEWER COMMENTS

We are indebted to the many people who took the time to review initial drafts and provide comments. In most cases, we were able to address these issues in the final version of this report. Nonetheless, reviewers have raised several important questions that we believe are worth further discussion.

Many reviewers felt that because our study was based on historical accident data rather than on instances where accidents did and did not occur (so-called “usage” data), our findings should be viewed with caution. We could not agree more. Certainly, there is little doubt that comprehensive information about all excursions into avalanche terrain would provide a number of valuable insights, particularly into what terrain and snow conditions are utilized by which types of recreationists, and which users are most at risk. But as we discuss in Section 3, such data is problematic when it comes to analyzing formal decision making frameworks. First, such data is not easily collected and to our knowledge, does not currently exist in any useable form for backcountry use the United States or Canada. Second, in order to be useful in quantitatively comparing the decision frameworks examined here, such data would need to be consistent across many variables and many observers, which seems impractical given the motivations and training of most recreationists. Data from ski resort and guiding operations, while it may be locally consistent, is not likely to be broadly representative of the snowpacks, locales, terrain, user groups or use patterns that typify most recreational backcountry use in North America. Finally, we would expect such data to contain significant inherent uncertainty. As students are routinely told in avalanche courses, the absence of an avalanche (or accident) does not mean that a particular slope is stable. It would therefore be problematic to categorically classify data from all outings that did not produce an avalanche as non-event data, since very slight differences in route choice or skier positioning may produce a very different outcomes. Thus, non-event data will always contain some (as yet unknown) uncertainty.

Given these uncertainties in non-event data, we believe that a conventional contingency analysis of the predictive values of decision frameworks would, at best, yield highly uncertain results. We find it notable that none of the European decision frameworks has, as yet, been accompanied by the publication of a formal contingency analysis of its predictive value. In the end, we seem to be left with accident prevention as the most expedient comparative metric between decision frameworks.

A number of reviewers commented on the need for decision frameworks to take into account the systematic errors and biases that are present in human decisions (referred to by some as human factors). Such errors and biases have long been recognized as playing a significant role in avalanche accidents among novices and experts alike. Starting in the 1970s, investigators such as Ray Smutek and Doug Fesler, and later Dale Atkins and Bruce Tremper, and more recently Ian McCammon and Laura Adams, have underscored the importance of human factors in decision making in avalanche terrain. Unfortunately, it is by no means clear how to eliminate, minimize or even effectively manage these factors, even to researchers examining essentially the same problem in other fields. We agree with our reviewers that human factors are an important aspect of decision framework design, and one that is worthy of further study.

While the goals of this study were rather modest, reviewers' comments suggest a number of issues that will be fertile ground for further investigation. Laura Adams outlines some of the factors that might influence the acceptance and utility of decision frameworks, such as social and cultural context, subjective risk assessment, and perceived value. Robert Bolognesi and Howie Schwartz mention the importance of designing frameworks that have educational value, and encourage further investigation of mobility characteristics of the various frameworks. There is little doubt that decision frameworks have the potential to prevent accidents in avalanche terrain, but the challenge that remains is to design tools that are both robust and practical.