APPLICATIONS OF RISK MATRICES FOR AVALANCHE FORECASTING AND EDUCATION

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ABSTRACT: Risk matrices are widely used in most fields that deal with risk. These are also called probability/consequence diagrams or FN diagrams (frequency/number). They have been only recently adopted into the fields of avalanche forecasting, avalanche education and backcountry travel. For the past few years most avalanche forecasting operations, public avalanche forecasts and avalanche educators in North America have been using the diagram we created in A Conceptual Model of Avalanche Hazard (Statham et al, 2010, 2018), which plots likelihood of an avalanche on the vertical axis and avalanche size on the horizontal axis as a way to conceptualize and visualize probability and consequence of avalanche hazard as well as variability and uncertainty. We use this diagram to plot where various avalanche problem types (avalanche characters) exist on the diagram. We can also use the diagram to plot hazard from a snow profile with the results of stability tests on the vertical axis and the mass of snow above the weak layer on the horizontal axis.

An important use of risk matrices is to plot the danger of the snowpack versus the danger of the terrain, such as the Avaluator 2.0 (Canadian Avalanche Centre, 2010). I use a similar diagram in my publications and classes to conceptualize appropriate specific terrain choices based on given avalanche danger ratings. In addition, in the most recent editions of my avalanche books, (Avalanche Essentials, 2013; Staying Alive in Avalanche Terrain, 3rd Edition, 2018) I also use various risk matrices to teach students how to judge the danger of specific terrain features by plotting steepness on the vertical axis (the closer to 39 degrees, the more likely an avalanche will occur) and terrain consequences on the horizontal axis (terrain traps, trees, cliffs or crevasses).

Finally, risk matrices have also been used to combine all the various factors that contribute to probability of a mishap (avalanche hazard, steepness, human factors, etc.) versus all the various factors that contribute to the consequence of a mishap (terrain consequences, rescue gear, rescue difficulties, medical and transportation issues, etc.). Jim Conway (2018) adapted a diagram from similar ones used by the U.S. Marine Corps specifically for use in avalanche guiding operations, as well as backcountry and rescue applications.

This paper is an overview of the many graphical applications of risk matrices for avalanche forecasting, avalanche education and backcountry travel.

KEYWORDS: Risk Matrix, Risk, Hazard, Probability, Consequence

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1. INTRODUCTION

Risk matrices are widely used in most fields that deal with hazard and risk. A good overview is covered in Statham (2018) so I in the interest of brevity I will not duplicate it here. In this paper, I present an overview of the many of the applications of risk matrices in avalanche forecasting, education and backcountry travel that are generally used in North America.

Starting in the late 1980's the Utah Avalanche Center informally used a probability-consequence approach as a way to determine the avalanche danger rating to augment our intuitive estimates. Using this method, we estimated the "sensitivity to triggers" (based on a 4-point scale: natural avalanches, easy human triggers, stubborn human triggers, explosive triggers) vs. the expected avalanche size. Meister (1994) published one of the first descriptions of avalanche hazard as a function of the probability of release and the expected avalanche size. In 2005, the European Avalanche Warning Services introduced the Bavarian Matrix (EAWS 2016), which combines the probability of avalanche release with the distribution of the hazard as a way to determine the avalanche danger rating. Combining these concepts with the ideas on avalanche character by Roger Atkins (2004), in 2005, the Utah Avalanche Center began using a graphic in our public avalanche forecasts that showed the avalanche character, likelihood of triggering and the expected size of the avalanche, which has since been adopted in various forms by other avalanche centers in North America and several other countries.

In the spring of 2008, avalanche specialists from the U.S. and Canada met in Canmore, AB Canada as a committee, chaired by Grant Statham, to rewrite the definitions for the avalanche danger scale. We quickly realized that we first needed to harmonize how we determined avalanche hazard and risk with standard practices in other natural hazards fields to include probability, consequence, exposure and vulnerability. After several more years of work, testing and feedback (Statham 2008) we produced the Conceptual Model of Avalanche Hazard (Statham, et al, 2010), (see Figure 1) and after more refinements it was recently published it in a peer review journal, Statham, et al, (2018).

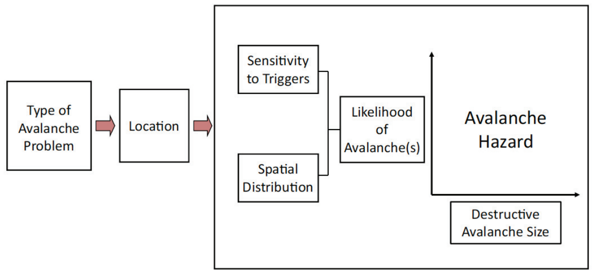

Figure 1, The framework of the Conceptual Model of Avalanche Hazard (Statham et al, 2010, 2018)

The concepts and procedures outlined in the Conceptual Model of Avalanche Hazard (CMAH) have been widely adopted in North America. It "provides a logical framework for organizing and analyzing crucial data and evidence that contributes to the avalanche hazard and informs risk mitigation decisions." (Statham et al 2018).

The success and adoption of the CMAH has motivated others and myself to use the concepts and graphical presentation in other aspects of avalanche education and communication including in my publications: *Avalanche Essentials* (2013), *Avalanche Pocket Field Guide* (2014) and most recently in the 3rd Edition of my book *Staying Alive in Avalanche Terrain* (2018). I address some of these applications below:

2. TEACHING AND FORECASTING FOR VARIOUS AVALANCHE PROBLEM TYPES

The CMAH is an effective way to teach and communicate various types of avalanche problems and graphically show the parameters used to determine avalanche hazard. For instance, avalanche forecasters and educators have always struggled with how to communicate to the public the characteristics of the type of avalanche that statistically causes most avalanche fatalities—called persistent slabs and deep persistent slabs in North America and old snow avalanches in Europe. These avalanche types are often less sensitive to human triggers (thus low probability and/or less frequent) yet if triggered, they tend to be very large and dangerous. We often describe them as low probability - high consequence avalanches, or sometimes low frequency – high consequence avalanches. This important concept is very difficult to communicate using words but much easier to communicate using a risk matrix graphic, (see Figure 2 and Figure 3). This diagram also communicates uncertainty or variability by the size and shape of the boxes. In addition, it's possible to use this diagram to plot snow profile data with the results of stability tests plotted on the vertical axis and the mass of the snow above the weak layer on the horizontal axis.

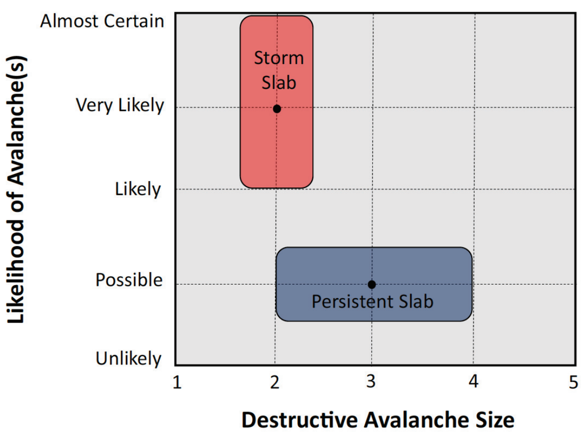

Figure 2, In one glance, different avalanche problem types can be displayed as a probability-consequence diagram (hazard increases toward the upper right corner). In addition, the size and shape of the boxes indicate uncertainty. Source: Statham et al, 2018.

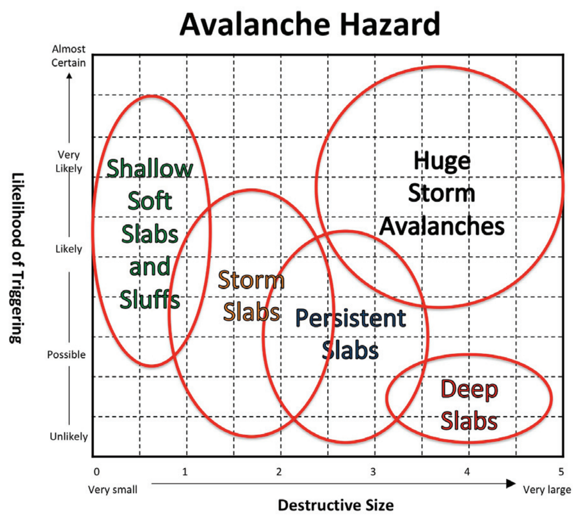

Figure 3, A conceptual diagram to show students the probability and consequence of various avalanche problem types. Source: modified by the author from Statham et al, 2008.

3. TEACHING ABOUT THE DANGER OF TERRAIN

In avalanche classes, I began using the probability-consequence concept and graphic to teach students how to recognize the danger of avalanche terrain and route finding. Traditionally, avalanche terrain has been taught to students using the 5-A's approach: Angle (steepness), Aspect as with respect to sun and wind, Altitude, Anchors, and Appearance (shape). Although I think this is still a good way to teach about terrain, I wanted to find a simpler way.

I have always struggled whether the concept of aspect and altitude should be taught in a terrain lecture or in a snowpack lecture because aspect and altitude controls what kind of snowpack occurs on that terrain. In addition, Vontobel et al, (2013) analyzed 700 human triggered avalanches in Switzerland and found little correlation between slope shape and avalanche activity, so I eliminated teaching about appearance, with respect to slope shape but retained teaching appearance as it relates to the consequence of an avalanche (terrain traps, crevasses, trees, cliffs, etc.). This left me with just three terrain factors—the truly the permanent, immovable parts of terrain that don't relate to snowpack—steepness, consequence and anchors. Anchors mean trees or rocks that help hold a slab in place.

Steepness correlates directly with the likelihood of an avalanche, which reaches a maximum at 39 degrees and decreases on slopes both steeper and less steep than 39 degrees (Harvey et al 2012). So terrain analysis begs to be displayed as a probability-consequence diagram (see figure 4). The third factor, anchors, is always difficult to teach because anchors are both good and bad; anchors help to hold the slab in place but if an avalanche occurs, then anchors suddenly become obstacles to hit on the way down. Thus thick anchors reduce probability but sparse anchors increase consequences and they can be plotted on the same probability-consequence diagram. I have found that this graphic helps students understand terrain.

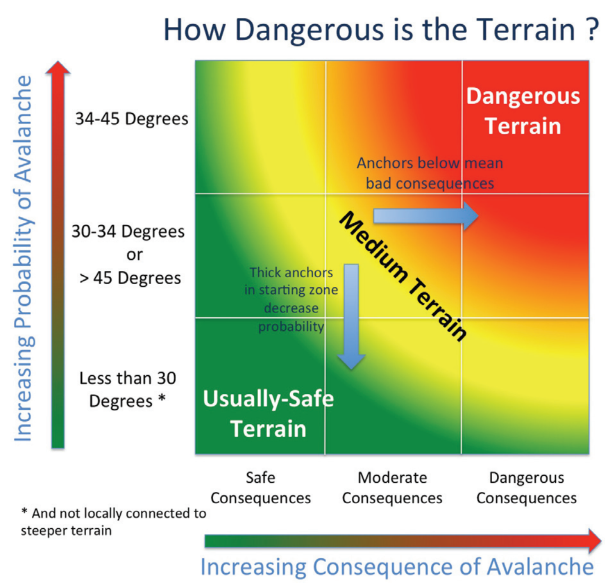

Figure 4, In avalanche education, I use this conceptual, probability-consequence diagram to show how to analyze the danger of avalanche terrain, by using only permanent terrain variables that don't depend on the snowpack.

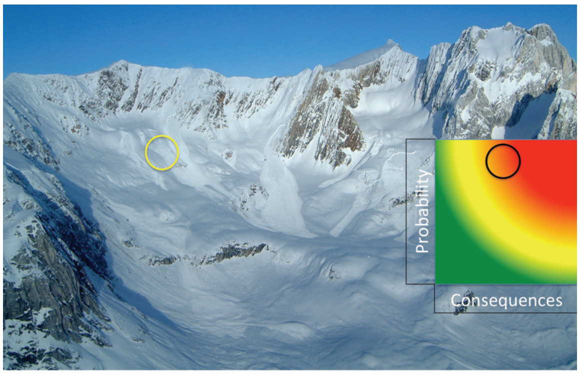

Photo by Roger Atkins

Figure 5, In teaching avalanche classes, I often show a terrain photo with a yellow circle on a specific terrain feature and ask students to use the laser pointer to plot the terrain on a probability-consequence diagram (black circle).

In an avalanche lecture, I often show students a photo of avalanche terrain and I draw a circle around a particular feature in the terrain, I hand the laser pointer to a student and ask them to locate that particular terrain feature on a probability-consequence diagram, which instantly shows them the danger of that terrain feature.

4. TEACHING ABOUT RISK AS THE INTERATION BETWEEN THE DANGER OF THE SNOWPACK AND THE DANGER OF THE TERRAIN

Many, if not most, avalanche accidents occur because people choose terrain that is not appropriate for the given snowpack conditions. It has always been difficult for avalanche educators and avalanche forecasters to communicate the simple concept that if the snowpack is dangerous, don't go to dangerous terrain; if you want to go to dangerous terrain, you can only do so if it has a stable snowpack. The Canadian Avalanche Centre developed the Avaluator (version 1.0 and 2.0), which addresses the relative danger potential of basin-scale terrain for trip planning purposes (version 1.0 and in version 2.0, users can add up points from both snowpack and terrain parameters to plot the relative danger of the combination (Figure 5).

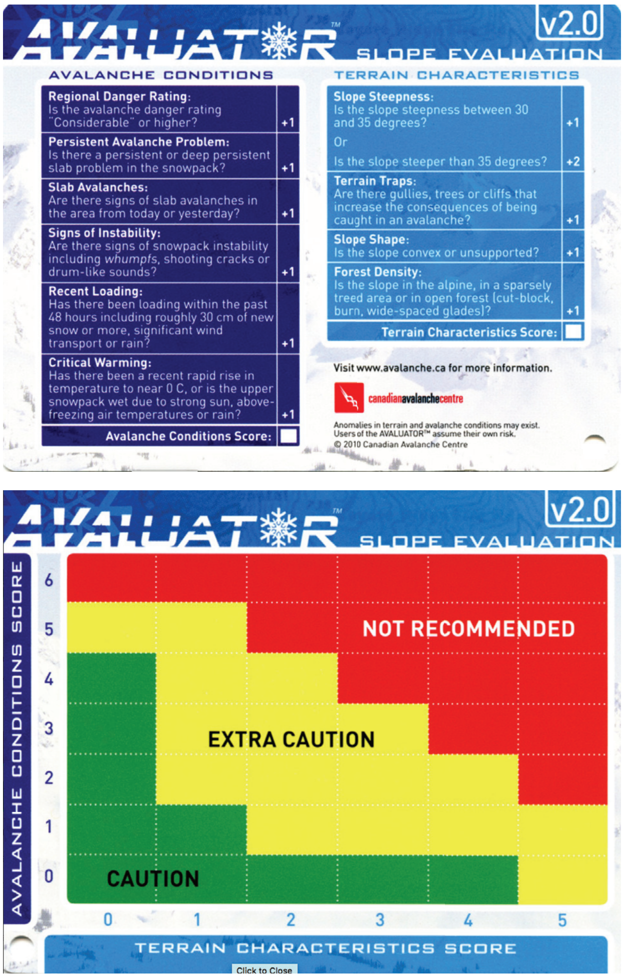

Figure 5

Avaluator, v2.0 (Canadian Avalanche Centre 2010)

In a very similar approach, but one that utilizes the local avalanche danger rating, I started using Figure 6 as a simplified, visual way to teach the choice of appropriate terrain for various avalanche danger ratings. I have found it to be an effective way to communicate this basic concept graphically and conceptually understand the tradeoff between the danger of the snowpack and the danger a specific terrain feature.

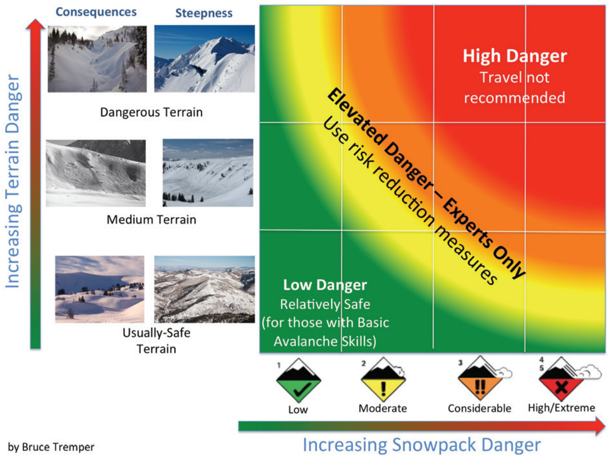

Figure 6, In this conceptual diagram, avalanche students can understand the tradeoff between the danger of the snowpack and the danger of the terrain. Colors in the box are conceptual and not based on data.

5. RISK AS A FUNCTION OF HAZARD, EXPOSURE AND VULNERABILITY

The standard approach in risk analysis applications is to separate risk into its components of hazard, exposure and vulnerability (Statham 2008, Statham and Gould 2016) and this approach works well for avalanche education, which I have incorporated into the 3rd Edition of Staying Alive in Avalanche Terrain (2018) as well as Avalanche Essentials (2013).

Hazard refers to the danger of the snowpack based on the probability and size of the expected avalanche. Exposure addresses the addition of people or property that could be harmed by the hazard. In the case of backcountry recreation, it means the route finding choices, the number of people exposed to the hazard and the low-risk travel techniques practiced by those exposed (such as one-at-a-time, belay ropes, slope cuts, etc.). Vulnerability is what happens to someone if they are caught in an avalanche, so it addresses factors such as avalanche rescue equipment and techniques, choice of terrain consequences, and medical, logistical and organized rescue circumstances. Risk can be reduced to zero by zeroing out any one of the three risk components: hazard, exposure or vulnerability. For backcountry travelers, we reduce risk by reducing a combination of the three components, for instance, our choice of snowpack can reduce hazard, our terrain choices can reduce exposure and our rescue equipment and techniques can reduce vulnerability.

6. COMBINE PROBABILITY AND CONSEQUENCE FROM ALL SOURCES

Jim Conway, a longtime, helicopter skiing guide and risk manager, has adapted a standard risk matrix used by the US Marine Corps to analyze the risk in helicopter skiing operations (Conway, 2018). In this application, all the sources of probability and all the sources of consequence are incorporated into one diagram (see figure 7).

Depending on the application, you can specify different parts of the risk matrix to indicate areas of acceptable risk, mitigation of risk and unacceptable risk. For instance, if you are leading a school group, the acceptable risk area would be in the lower left hand corner, a backcountry skiing or snowmobiling group might expand the area of acceptable risk into a wider area in the lower left hand corner, finally, if you are an extreme athlete doing a video shoot, your area of acceptable risk my be even wider.

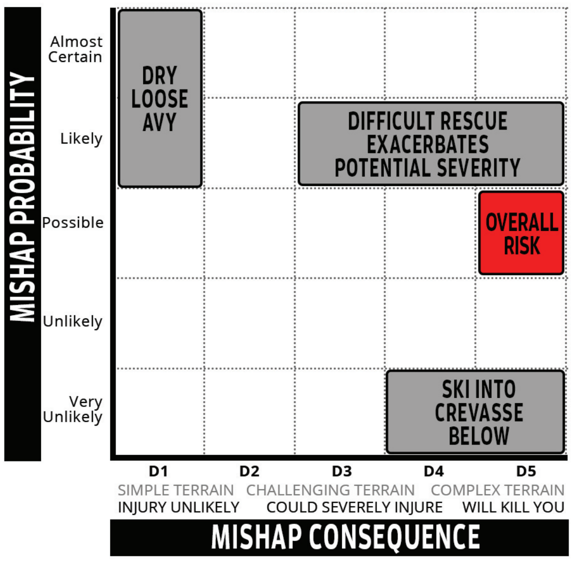

Figure 7, A probability-consequence diagram from the US Marine Corp adapted to the risks in helicopter skiing by Jim Conway (2018). In this way, you can combine all the sources of probability of a mishap with all the sources of the consequence of that mishap. Some examples of consequence are displayed on the horizontal axis but other factors can be considered as well. Depending on the application, you can define the areas of acceptable risk, mitigation of the risk and unacceptable risk.

7. CONCLUSION

As stated in Statham et al (2018), “This Conceptual Model of Avalanche Hazard identifies the key components of avalanche hazard and structures them into a systematic, consistent workflow for hazard and risk assessments.” Building upon the CMAH framework, others and myself have created additional, useful, graphical tools for avalanche education, avalanche communication and avalanche risk management.

These include conceptual, graphical diagrams to:

1. Plot various types of avalanche problems on a probability - consequence diagram to help communicate difficult concepts for students and the public such as low probability (or low frequency) – high consequence avalanches.

2. Use the same diagram to plot hazard from a snow profile with the results of stability tests on the vertical axis and the mass of the snow above the weak layer on the horizontal axis.

3. Plot the relative risk of terrain and snowpack variables (Avaluator v2.0, 2010).

4. Use a similar 2-d plot to visualize the choices and tradeoff between the danger of the snowpack based on danger rating versus the danger of the terrain.

5. Plot specific terrain features on a conceptual, probability-consequence diagram to visualize the effects of steepness, consequences and anchors.

6. Understand the components of avalanche risk from the perspective of hazard, exposure and vulnerability

7. Visualize overall risk by plotting the probability and consequence of various kinds of mishaps on the same diagram.

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