

A NOVEL APPLICATION OF WEIGHTED RISK ANALYTICS IN ASSESSING SNOW STABILITY TO PROVIDE CONDITIONAL ROUTE OPTIMIZATION

Zachary E Buzaid^{1*}

¹Wentworth Institute of Technology, Boston, MA, USA

ABSTRACT: While an array of modern gear allows skiers to be better prepared in the event of an avalanche, there is a lack of adequate technology to aid in a skier's risk assessment of a particular surface so that a slide is never triggered. This algorithm quantifies the risk of an avalanche based on slope, wind, recent precipitation, sunlight, snow albedo, temperature trends and terrain traps. Using GIS techniques and optimization methods, this algorithm provides a visual representation of a feasible region (optimal route) in which the risk of an avalanche occurring is below a certain user-set threshold, while also displaying the entire risk map of the surface in an easily understandable format. This algorithm was tested in conjunction with the Mount Washington Avalanche Center's snow stability report on April 15, 2014 and yielded an almost identical risk rating for all subsections of Tuckerman Ravine. Through constant refining and collaboration, I aim to provide users with a tool that acts as a complement to existing avalanche evaluations in order to confirm projections and aid in a reduction of human-triggered slides.

KEYWORDS: Risk Management, Route Optimization, Snow Stability, Predictive Analytics

1. INTRODUCTION

In an age where backcountry skiing is becoming more accessible to the average skier, there is a growing demand for the introduction of easily attainable risk management tools and methods. Currently, there are many standard practices in place for testing snow stability that revolve around examining a certain segment of a slope that resembles that of the feature you wish to interact with (i.e. Snowpit Testing). While this is certainly an indispensable test that should be done regardless of any overarching knowledge or technology possessed, it is also susceptible to many misunderstandings and false confidence scenarios. The idea behind this algorithm is to have a foundation on which to judge and compare your other stability test results.

The algorithm processes real-time information provided by the user for the area being observed (time of year, recent precipitation, winds, etc.) and provides a map of the entire surface with areas of particular slide susceptibility highlighted in distinguishable colors. Future scalability of the algorithm

is contingent upon a healthy API communication with a GIS package, as for now the only surface being processed is that of Tuckerman Ravine on Mt. Washington.

Whereas there are multiple avenues for accuracy improvements (i.e. below-surface modeling refinements), this algorithm was initially created to see what was possible with basic calculus and analytics. It is exciting to see the impact and potential that a tool such as this has when used in conjunction with traditional safety measures.

2. ALGORITHM ORDER OF OPERATIONS

In order to understand how the algorithm comes together and produces a cohesive value for each subsection of a slope, it is first necessary to have an idea of the logistical order of operations.

2.1 *Voxelization*

The algorithm needs to first be handed the geographical data for the area it is going to analyze. This is done through a process called voxelization (the act of segmenting a surface into digestible subsections, better known as cells). Once the area is broken down into cells, we can assign each one its own unique characteristics. The values that are unique to a cell are its slope, direction, and whether there is a terrain trap or not (rock, tree, cornice, etc.). The algorithm can't proceed without these three numerical values. From here, the algorithm

* *Corresponding author address:*

Wentworth Institute of Technology;
Boston, Ma, 02115;
tel: 1-203-733-2933;
email: buzaidz@wit.edu;

can now apply its formulas systematically to ensure that each cell receives a unique, accurate, and understandable value.¹

2.2 Systematic Processing

Each cell that is formed from the geographical representation of the slope (essentially splitting a map into tiny processable pieces) is then placed into an array (lined up to be handled one by one). The algorithm then takes each cell's values in the array as an input, one at a time, and then provides that cell with a Final Risk Value (FRV). Based on the cell's FRV, it receives a color gradient to symbolize the amount of risk within that voxel. An example of the end product is shown below:

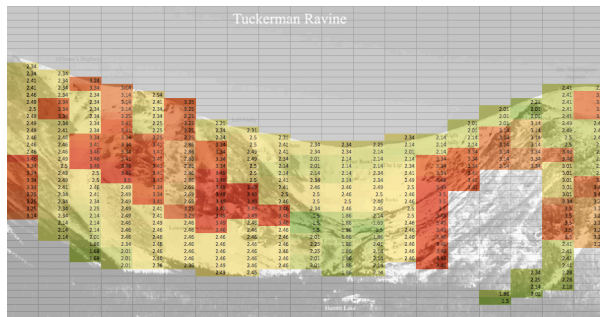


Fig. 1: Feasibility analysis for Tuckerman Ravine

2.3 Route Optimization

The process of conducting a feasibility analysis to find the optimal route down the mountain is the final step in the algorithm. This functionality is diverse in the sense that the route can be based off of any one of the calculated values. For instance, if the user wanted to ski the steepest slope on the mountain, then we would use slope as our conditional variable. More commonly, however, this route optimization method is used to find the path of least risk when trying to avoid triggering a slide. An example of a calculated route is shown in the figure below where the route is depicted by the descending green flag emblems (possibly hard to see in this smaller format):

¹ It should be noted that a cell could have any dimension, as long as it has the 3 fundamental values. For the test case, the cells were roughly 60 x 20 ft. wide. It goes without saying that the smaller the cells are, the more accurate the output will be. Smaller dimensions of a cell, however, are contingent upon very accurate data retention.

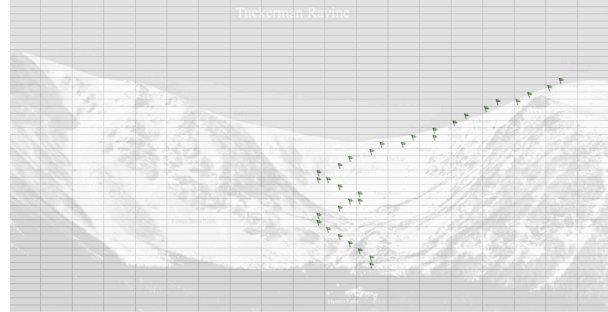


Fig. 2: Route optimization for Tuckerman Ravine

With images like the two shown here, a backcountry-goer has the ability to see the mountain as a whole and not just from the inside of a snowpit. If they find that their stability assessment is considerably lower than they initially believed, it may be because they happen to be in a low risk section compared to the rest of their planned route, and vice-versa. The key to avoiding an avalanche is to possess as much information about the route as possible in the shortest amount of time, which this algorithm aims to do. The next step is to discover how the algorithm comes about calculating the risk values for each cell.

3. INPUTS & VARIABLES

This section will describe, at a high level, the individual variables that are analyzed by the algorithm.

3.1 Sunlight

The sun produces radiation, which then has the ability to heat the surface. Although snow typically boasts a relatively high albedo (the percentage of radiation reflected by a surface), the effects of sunlight for an extended period of time on any snow-covered surface can be drastic. The amount of daily sun exposure that each section of a mountain receives varies considerably based on its slope and direction. Within this algorithm, the time of year, slope, longitude, latitude, elevation, and albedo are all taken into consideration using a formula constructed in the paper *Analytical Integrated Functions for Daily Solar Radiation on Slopes*. Ultimately, this formula outputs a numerical value that allows us to assess the intensity of the thawing process taking place on a given snow-covered area.

3.2 Temperature

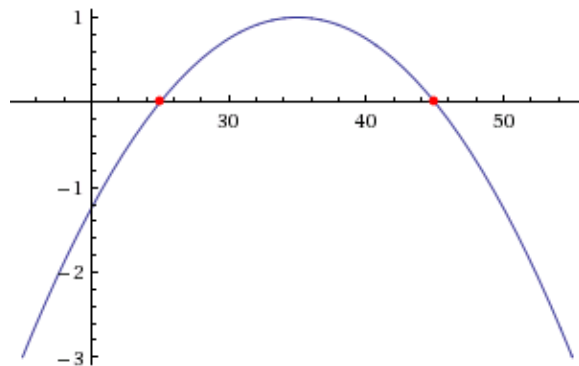
Temperature is another aspect that is commonly associated with sunlight/radiation, but is a factor

that can be just as effective on an overcast day. The algorithm takes as inputs the temperature history for the past 36 hours in 6-hour increments. This allows us to take note of any temperature spikes that would cause need for concern, as well as observe the average temperature for this period to discover if there is a heightened warm-weather related risk (a consistent above-freezing trend, or a thawing period).

3.3 Slope

When conducting stability tests, the most common tool for calculating slope is the inclinometer. An inclinometer is an asset that every backcountry-goer should have in their tool belt, but it is also a tool that if used improperly can yield very misleading results. The ability to stream accurate slope information via GIS is extremely beneficial when analyzing an entire area, and not just one small subsection of a route, which is almost guaranteed to deviate at several points throughout its length.

It is commonly understood that an avalanche is extremely unlikely to take place on slopes angled below 25° and above 45°, with the most prone being in the middle of the two around 32-38°. This characteristic is fairly easy to model with a simple function, where the variable x = slope of the cell:



$$\text{Slope Function} = (1/100) * -(x - 35)^2 + 1$$

As visible from the graph above, if the value of slope (x) is above 45 or below 25 (the function's roots), then the function does not yield a significant value. When the slope is equal to 35 (± 3 degrees) then it's at the maximum y -value (risk). This function grabs the slope from each cell's fundamental characteristics that were mentioned earlier, and then assigns each cell a slope numeric risk value that is handled in the FRV (Final Risk Value) calculation of the cell in the last stage of the order of operations.

3.4 Precipitation

Precipitation can come in the form of snow or rain, both of which play an extensive role in a slope's stability (i.e. storm slabs, permeation, rain crust, etc.). The algorithm takes as input the most recent precipitation event, the amount received, and how long since occurring. This information gives us an idea of whether or not the snow has "settled", which is valuable criteria when considering the possibility of wind loading or a storm slab. It also helps give perception to the idea of a late-season permeated layer from rain exposure, all of which are factored into the FRV.

3.5 Wind

Wind-loaded features can be ticking time bombs, and recognizing an area that is under load is not exactly a walk in the park. Loaded features can blend into other surfaces seamlessly, making for a devastating trigger if knowledge of recent wind patterns is not obtained. The algorithm takes account of the amount of recent snow and whether or not it is transferable. What makes snow most transferable is a dry and unsettled consistency, as opposed to heavy and wet. Pairing recent precipitation characteristics with wind speed and direction allows us to discover which sections of the slope are most affected by the wind-aided transportation of snow, and how to adequately represent this characteristic through the FRV.

4. THE FINAL RISK VALUE

4.1 The Formula

The high-level format of the equation follows, where i is the current cell, or voxel, in the array that we are processing, and TRA meaning "Total Radiation Absorbed":

```
FinalRiskValue[i] = terraintraps[i] + SlopeRisk[i] +
Today'sTRA[i] + windRisk + warmweather-
risk+recentSnowRisk;
```

4.2 Calculating the Final Risk Value

In order to calculate the FRV (Final Risk Value) that has been mentioned throughout the manuscript, the algorithm must gather all the products from the formulas and determine how much each will contribute to the final risk assessment. The best way to comprehend this process is to think of each variable as part of a point system. For every variable in the last section, the maximum contribution they can have towards the FRV is +1, with the minimum contribution being +0. Upon adding up

all the products from each formula, we will have a cumulative sum of calculated risks that have been combined to form a numeric value that is easily comprehensible.

The algorithm also recognizes scenarios where not every variable needs to be at its maximum value in order for a high avalanche risk to be present. This is why if any one variable is at its maximum value, it receives a relative “boost” to emphasize that this area is particularly susceptible to slide activity (i.e. a section of the mountain that is particularly wind-loaded). It would be foolish to think that an avalanche isn’t going to take place unless there is the “perfect storm” (aka a maximum risk value for all calculated variables).

4.3 Understanding the Final Risk Value

Most avalanche centers use a scale, commonly accompanied by a color gradient, that will describe a risk rating of a particular slope for the day in question. A standard scale will typically look something like the following:

Tbl. 1: Avalanche Risk Ratings

<i>Risk Level</i>	<i>Color</i>
Low	Green
Moderate	Yellow
Considerable	Orange
High	Red
Extreme	Black

Tbl. 1: Standard avalanche risk ratings and the colors associated

In order to provide a scale that was easily understandable and required minimum transitional effort, the industry standard was mimicked. This means that a FRV of 1 is green, 2 is yellow, 3 is orange, 4 is red, and 5 is dark red (as black would make the cell no longer transparent). Using this format allows for the end user to look at the risk map and quickly associate certain areas with particular risks based on the gradient they are displaying.

5. CONCLUSIONS

The Avalanche Algorithm has proved to be a fairly accurate tool in the test cases that it has been provided. It has the ability to calculate risk that could otherwise go unnoticed, and it also has the ability to confirm predictions. It uses basic formula

las and modeling techniques to assemble data in a digestible format that a non-tech-savvy user could clearly understand.

The algorithm has many opportunities for modeling and input automation. Not every person is well aware of the weather for the past 36 hours in the area they are exploring, and not every measurement taken is guaranteed to be accurate. This margin of error has the potential to be minimized through the use of a NOAA API call with latitude & longitude, where the weather data is automatically handed to the algorithm instead of relying on the user’s input. The modeling of wind loading also has a great potential to be improved, as well as incorporating faceting, surface hoar, and depth hoar.

From here, the algorithm can only become more accurate and more user friendly. It is exciting to think where it will progress to in a few months time.

ACKNOWLEDGEMENTS

I would like to acknowledge Rachel Maitra, the Professor of my Operations Research class. Without her guidance and recommendations, I would not have been able to have this project to where it is now.

All geospatial data was provided by the NH Forest Service’s public database. All avalanche reports for Tuckerman Ravine that the algorithm was compared to are from the Mount Washington Avalanche Center. Their daily reports provide great depth and excellent safety information for those interacting with the terrain.

REFERENCES

- O’Bannon, A 2012: *Allen & Mike’s Avalanche Book: A guide to Staying Safe in Avalanche Terrain*. Globe Pequot, 5 pp.
- Allen, R and Trezza, R and Tasumi, M., 2005: *Analytical Integrated Functions for Daily Solar Radiation on Slopes*. *Agricultural and Forest Meteorology*, Volume 139, Issue 1, Pages 55-73
- Table 1: Based off of the North American Public Avalanche Danger Scale. Provided by the Colorado Avalanche Information Center: <http://avalanche.state.co.us/forecasts/help/avalanche-danger/>