A HISTORICAL ANALYSIS OF THE STANLEY AVALANCHE AREA WITH IMPLICATIONS FOR PREDICTING ROAD-HIT AVALANCHES, BERTHOUD PASS, COLORADO

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ABSTRACT: The Stanley avalanche area is commonly regarded as one of the most dangerous to impact a roadway in the state of Colorado. Weather and snowpack structure play a key role when making road closure and avalanche mitigation decisions. My research aims to quantify those parameters of variables that are typically needed to forecast an avalanche from the Stanley that is large enough to hit and cover U.S. Highway 40 with debris. I gathered avalanche occurrence data from 1970-2008 on the area and related it to precipitation and wind patterns. Results show that half of all avalanches to hit U.S. Highway 40 occurred during the short time frame from December 16 to January 31. The weather conditions preceding a road-hit avalanche included heavy precipitation and strong northwest winds. Avalanche events that did not hit the road were preceded by lighter precipitation and lighter winds from the west.

1. INTRODUCTION

Avalanche forecasting is a decision making process with the goal of limiting the loss of human life and minimizing adverse affects on the economy. The Stanley Avalanche Area has the highest avalanche hazard index of any slide path on Berthoud Pass (Mears, 1995). During the last 14 years, the Colorado Avalanche Information Center (CAIC) has worked with the Colorado Department of Transportation (CDOT) to forecast avalanches in the Berthoud Pass area. This effort has reduced the number of avalanches that hit U.S. 40, but has not eliminated the threat from avalanches (Metzger and Schaefer, 2009). My research aims to make past avalanche occurrence data available to forecasters, provide an analysis of avalanche activity in the Stanley, and highlight some of the specific conditions common to avalanches that hit the road and cover it with debris.

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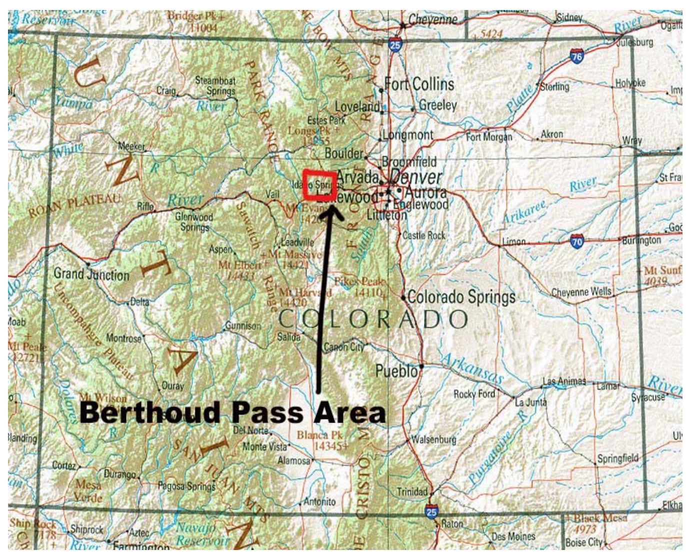

Figure 1: State of Colorado. Arrow points to the Berthoud Pass Area

2. THE SETTING

The Stanley Avalanche Area is located on the east side of Berthoud Pass above U.S. Highway 40, in the Front Range of northern Colorado (see Figure 1). Berthoud Pass sits at an elevation of 3446 meters above sea level (ASL) on the continental divide. The snowpack here is typical of those that form in a continental snow climate (Mock and Birkeland, 2000). A continental snow climate is characterized by a low rate of precipitation, cold temperatures, and lots of post storm wind re-deposited snow. The depth is typically shallow and variable, and the layering pattern is typically a strong over weak structure. The avalanche activity occurs most often post storm, hours to days to weeks after. The stability of the snowpack is often very slow to fall (AIARE 2007).

An avalanche area is a location comprised of one or more avalanche paths. An avalanche path is defined as a fixed location where avalanches occur (McClung and Schaerer, 2006). Each avalanche path contains a starting zone, a track, and a runout zone. The Stanley avalanche area includes 3 paths (see Figure 2). The starting zones face southeast. The Stanley paths can run up to 830 vertical meters from the top of the highest portion of the starting zone at 3780 meters ASL to the West Fork of Clear Creek at 2950 meters ASL. The eastern portion of U.S. Highway 40 at Berthoud Pass cuts across the base of Stanley Mountain and crosses Stanley Avalanche Area in two locations. The first is where the road runs next to the West Fork of Clear Creek at roughly 2956 meters ASL, and second is where the road cuts across the track of all three paths at roughly 3085 meters ASL. Only the main path is known to have hit the lower crossing, while all three paths routinely hit the upper crossing.

3. BACKGROUND

The CAIC works with the CDOT to help with critical decisions on when to close the roads and perform avalanche mitigation. The CAIC's Eisenhower Tunnel office works with CDOT's Region 1 to address avalanche issues on Cameron Pass, Berthoud Pass, Loveland Pass, and the I-70 Corridor from Georgetown to Vail. When the forecasters deem it necessary to perform avalanche mitigation, the portion of the highway affected is closed. CDOT personnel place explosive charges in the starting zone in order to disturb weak areas in the snowpack with the aim of triggering a controlled avalanche. (McClung and Schaerer, 2006).

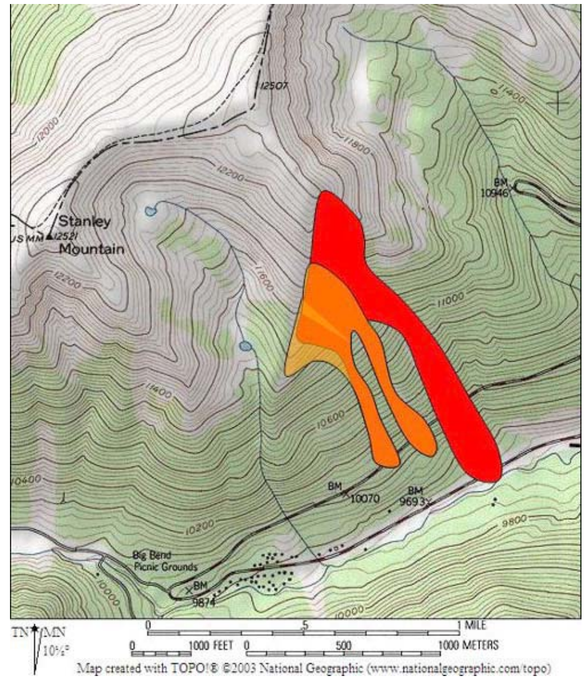

Figure 2: Topographic map showing the Stanley Avalanche Area on Berthoud Pass
Photo: avalanchemapping.org

Explosive delivery methods for the Stanley Area include dropping explosives from a helicopter, shooting the zone with a 105mm Howitzer or shooting with an Avalauncher. Afterwards, the highway can be safely reopened to motorists. Removing debris from the highway substantially increases the amount of time the road is closed. The longer a road closure is in place, the greater the economic losses increase. (Blattenberger and Fowles, 1995).

The Stanley has been the culprit of a number of accidents. The Stanley hit the road, killing one motorist in 1945. On December 28, 1973 a hard slab avalanche hit, buried, and injured a motorist. On January 9, 1988 a hard slab avalanche hit and buried a motorist but he was not injured. The most recent accident occurred on January 6, 2006 when a natural hard slab avalanche pushed 2 cars off the road, critically injuring 1 of the 8 people involved.

Weather and snowpack are the architect for avalanches (Scheler et al., 2004). Stability evaluation can be defined as estimating the probability that an avalanche can occur. This incorporates the bonding strength of the various layers that make up the snowpack. Avalanche forecasting is a process that combines field experience and empirical knowledge of the snowpack structure with weather forecasting in order to make an estimate of the avalanche potential. The accuracy of the forecast can be improved with experience in the region and with statistical analysis of historical data. (McNeally, 2006)

My primary research objective is to evaluate if an avalanche will hit the road or not based on hindsight forecasting of weather variables. “What we would like to know is whether an avalanche is likely on a certain slope, and, if so, what sort of avalanche it will be” (Buser, 1987). This objective further defines and classifies the problem that I am attempting to do, to pinpoint the size of avalanches and their runout zone in a specific avalanche path.

4. DATA

The data for this research came from a number of different sources. The avalanche occurrence data came from the CAIC’s highway avalanche forecast office at the Eisenhower Tunnel. Each mitigation mission is recorded along with the results on a shot record. The shot records contain information such as the date, time, location, shot number, and results. When an avalanche ran as a result of mitigation, measurements were taken to the standards of the Observational Guidelines for Avalanche Programs in the U.S. (Greene et al., 2004). The event characteristics include the type, trigger, size, snow properties, dimensions, location, and terminus. The shot records from 1996 to 2008 were entered into Microsoft Excel. The quality of the data from this source is dependable, as expert forecasters have recorded it using established metadata protocols. The data from this source is thus complete and of high quality.

I obtained avalanche occurrence data from 1970 to 1995 from Dale Atkins, a previous avalanche forecaster for the CAIC. Of these 26 years, there are 8 years with data that is either missing, or no avalanches have been recorded. The National Forest Service Rocky Mountain Research Station conducted data collection during this time. Observations from 1970 to 1989 were taken by a single expert observer 99.9% of the time(Atkins, 2009). From 1990 to 1995 four to six different observers took the observations. After 1995, the data set became inconsistent. The main difference between this dataset and the former set, from 1996 to 2008, is that much less avalanche mitigation occurred from 1970 to 1995. These latter data have more recorded natural avalanche activity, while the set from 1996 to 2008 was characterized by much more artificial avalanche activity.

Weather data was gathered from the Berthoud Pass automated weather station, run by the CAIC. The station is located at 3615 meters ASL, and about 2 kilometers east-northeast from the top of the Stanley. Data is sent in hourly increments to the MesoWest website. These data include the time, temperature, dew point, relative humidity, wind speed, wind gust, wind direction, and a quality check. The station has been recording hourly data since December 2001. The weather data from this station is of high quality and consistency. I removed any data with a quality control check of “suspect” from the data set. I compared data flagged as “caution” to the nearest “OK” data, and decided whether or not to keep it based on how realistic it looks. Data that registered as “OK” has passed all quality control checks, and is included in the analysis.

Precipitation data came from the National Resource Conservation Service’s SNOTEL network. The “Berthoud Summit” station is located at 3444m ASL and about 2.4 k northeast from the top of the Stanley Area. Snowfall measurement is far from standardized and precise. A typical SNOTEL site consists of an air temperature sensor, precipitation gauge, and a snow pillow. A snow pillow is a square shaped piece of stainless steel or rubber that contains antifreeze liquid inside it. The force of snow on the pillows exerts a pressure on the liquid that in turn calculates a weight with an electric measuring instrument. The instrument converts the weight of the snow into snow water equivalent (SWE). SWE is the amount of water in a given volume of snow (Williams, 2008). This information is sent into the atmosphere through radio signals. The radio signals are reflected off of meteors, and picked up by one of two master stations. This is known as meteor burst communications.

The SNOTEL site is not located in the starting zone of the Stanley, and therefore assumptions must be made when relating to the height of snow in the Stanley. The SNOTEL site is located in a fairly protected area. There are trees nearby that provide surface roughness and slow the wind down (Greene, 1999). The starting zone of the Stanley is very exposed to the wind. These differences are important to note, and result in differing snow depths and snowpack structures from each site.

5. METHODS

I evaluated all the weather variables and settled on three important ones; wind speed, wind direction, and new precipitation. This decision is based on part because it was demonstrated by McCollister (2004) that these three variables appear to be simplistic and effective. I am using wind data from the 12 to 72 hours prior to a control mission. The average wind direction and speed were analyzed from 12, 24, 48 and 72 hours prior. I used accumulated precipitation from 120 hours before a control mission. The accumulated precipitation was used rather than the new snowfall, because Davis (et al., 1999) found new precipitation to be slightly more important than new snowfall. The amount of precipitation is added together for the time period of interest. Accumulated precipitation will be analyzed from 48, 72, and 120 hour time periods. The 24-hour time period could not be used because of the way the data was recorded, and the varying times of day that avalanche control was performed.

The data is structured in such a way that each avalanche occurrence has its own record. There are a number of cases where more than one avalanche has occurred in the same day. In order to make each occurrence unique I assigned an identification number for each avalanche recorded. These go in chronological order from the first one in 1970. This will also give the forecaster a unique perspective as to how many slides have been recorded in the Stanley. Data were analyzed with the use of Microsoft Excel and Stata, although a goal is to develop an efficient way of interpreting data in a way that is beneficial to avalanche forecasters. In averaging wind directions, it was necessary to convert the direction in degrees to radians, and then convert back. Wind speeds were averaged for each time period. Precipitation was added for each time period.

6. RESULTS

The temporal distribution of avalanche occurrences, both road hit and non-road hit avalanches can be viewed from Figure 3 and 4. 50% of all avalanches that hit the road from 1970-2008 occurred in the December 16 to January 31 time period. 76% of all road hit slides that were recorded occurred in the December 1 to February 28 time period. 26% of all avalanche occurrences in the Stanley are either road hits or came to the edge.

We can see from Figure 4 that non-road hit avalanches tend to be randomly distributed. Figure 3 shows that the distribution of road hit avalanches takes the form of a normal distribution. There is a large amount of avalanches that occur during the April 16- April 30 time period, but don't hit the road. This is interesting, as one might expect more avalanches that could hit the road to occur as a result of these spring storms.

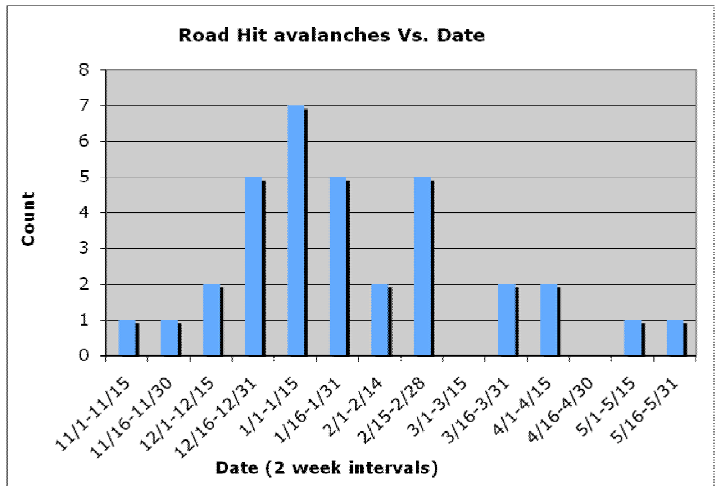

Figure 3: Histogram of Road Hit avalanches Vs. Date in two week increments in the Stanley, 1970-2008

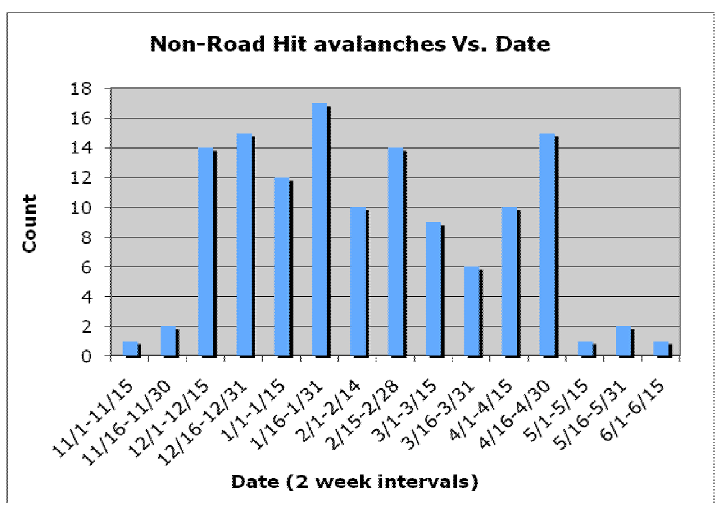

Figure 4: Histogram of Non-Road Hit avalanches Vs. Date in two week increments in the Stanley, 1970-2008

Statistics suggest that most road hit avalanches in the Stanley area occur when a significant portion of the starting zone releases (see Figure 5). Unfortunately, forecasting how much of the starting zone will release is a difficult question. This goes beyond the scope of this paper, but brings up a question of how weather and snowpack conditions contribute to the percentage of starting zone release.

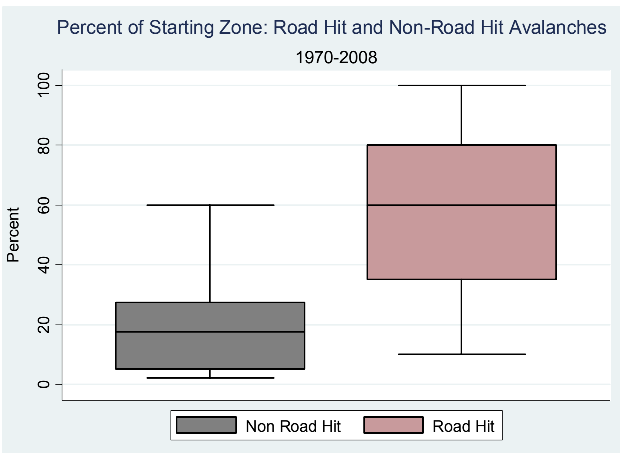

Figure 5: Box Plot showing differences in percent of starting zone release, non-road hit and road hit avalanche occurrences in the Stanley. The middle lines are the average, the upper and lower ends of the boxes are the 75th and 25th percentiles respectively, and the whiskers are the outliers.

The greatest difference in wind direction between a road hit and a non-road hit avalanche occurred during the 24-hour period prior to the avalanche. This was a difference of 41 degrees, from west to northwest. The average of the road hit avalanches have occurred consistently after a more northwesterly flow than the non-road hits (see Figure 6) Distinctions in wind direction may be an effective parameter for forecasting avalanche activity if the forecaster uses it from the 24-hour time period prior to a possible control mission.

The greatest difference in average wind speed occurred during the 72-hour period prior to the avalanche, where road hit avalanches had on average 9.0 kilometers/hour greater speeds. Interestingly, the least difference occurred during the 12-hour period prior to the avalanche. This 2.1 kilometers/hour difference was not enough to make any distinctions between the two wind speeds with regard to avalanche activity. Table 1 shows on average, road hit avalanches occur after wind speeds that are consistently stronger than non-road hit avalanches, though none are statistically significant at the 68% confidence interval.

	Non-Road Hit	**Road-Hit**	**Difference**
Wind Direction (Degrees)			
72 hour	303	305	2
48 hour	285	307	22
24 hour	273	314	41*
12 hour	284	309	25
Wind Speed (kilometers/hour)			
72 hour	26.1	35.1	9.0
48 hour	26.6	34	7.4
24 hour	27.2	32.8	5.6
12 hour	28	30.1	2.1
Precipitation (millimeters)			
120 hour	29.0	34.5	5.5*
72 hour	18.6	24.4	5.8*
48 hour	11.2	17.5	6.3**

Figure 6: Difference in Means for three variables

- *** = Statistically significant at the 68% confidence interval**
- **** = Statistically significant at the 90% confidence interval**

Precipitation differences between road hit and non-road hit avalanches lie within the 5.5 to 6.3 millimeter range. The greatest difference occurred during the 48 hour time period prior to the avalanche. We can see from Figure 6 that it took consistently more precipitation to produce a road-hit avalanche in the Stanley than a non-road hit avalanche. All of the differences in means are statistically significant at the 68% confidence interval, and the 48-hour period is significant at the 90% level.

7. CONCLUSION

The purpose of this study was to quantify the parameters of variables that are typically needed to produce an avalanche that is large enough to hit and cover U.S. Highway 40 with debris. The strongest variable that can be used for predicting road-hit avalanches is new precipitation in the 48-hour period prior to avalanche control. Avalanches that occurred in the Stanley that don't hit the road had an average of 11.2 mm of precipitation 48 hours prior. Avalanches that hit the road had an average of 17.5 mm 48 hours prior. Other variables that may be effective in forecasting road-hit avalanches are precipitation from 120 and 72 hours, as well as wind direction from 24 hours prior to control work. Wind speed was found to have no statistical significance in discriminating between whether an avalanche will hit the road or not.

Mock and Birkeland (2000) found that limited new snowfall was sufficient to overload old layers of fragile depth hoar on Berthoud Pass during the 1976/77 season. Avalanches releasing on this layer often ran on the ground, involving the snowpack from the whole season (Mock and Birkeland, 2000). The ground was the bed surface for many of the road-hit avalanches in the Stanley, suggesting that basal faceted layers, or depth hoar, are the weak layer for many of the larger avalanches that occur in this area. This is supported by the fact that 50% of all road-hit avalanches have occurred during the short period from December 16 to January 31 over many seasons, when basal depth hoar is conventionally found to be pronounced and reactive. This suggests a transitional period of the continental snowpack here from the typical weak structure to a more stable one later. Forecasters aiming to predict road-hit avalanches in the Stanley must pay particular attention during the period from December 1 to February 28, because historically 78% of all road-hit avalanches occurred during this time.

The use of a GIS as a database for avalanche events and control practices for avalanche forecasting programs is highly recommended, but can only be utilized if and when data is archived and maintained in a digital database. If the data is readily available to work with, forecasters can easily compute statistics in a program such as Stata, or R, before the start of each season. This will both enhance the understanding of the path in question, and refresh the forecaster's memory. The process of entering 13 years of data manually into Microsoft Excel was both time consuming and frustrating. The programs that can benefit most are those that have a number of reliable and well maintained automated weather and SNOTEL stations that can be closely correlated to the starting zone of the path/s in question. In addition, constant and consistent maintenance is needed for data to be easily analyzed. Further research is needed to utilize a GIS to aid in data retrieval and analysis. It has been shown that it is possible to take an approach that produces a probability of a road-hit avalanche, while maintaining a database of events and control practices that can be viewed efficiently for aid in avalanche forecasting. Future research can apply a GIS for hypothesis testing and visual exploration of the temporal distribution of avalanche events in relation to weather patterns for a single path. This will help solve the question of how much new precipitation and wind redistribution are necessary for an avalanche to be initiated in a single path that will be large enough to hit and cover the road, or a structure with debris. Above all, if done correctly, it can be operationally utilized.

Acknowledgements: Thanks to everyone at the CAIC, especially; Ethan Greene for facilitating the research and reviewing the paper, Spencer Logan for advice and review, Lee Metzger and Stu Schaefer for their knowledge and support.

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