Avalanche Frequency by Elevation, Aspect, and Predicted Human Interactions in the Central Wasatch Range

By Liam McGee

Abstract

Backcountry travel and avalanche science have been rising in popularity and necessity for the past years, especially in hotspots of winter travel such as the Central Wasatch Range in Utah. While much is known of slope angle analyses and how various slope angles affect and propagate avalanches (slides), much less is known about other factors' specific role in the frequency of avalanches. With professionally and recreationally reported data, this paper attempts to look into avalanche trends in the Central Wasatch Range, digging into known factors that influence avalanche terrain: namely elevation, aspect, season, and human interaction. In order to investigate these ideas, data was taken from the UAC and UDOT in which location, aspect, elevation, and time of year was recorded. To determine human usage, data was taken and summarized from winter travel sensors set up by the Wasatch Backcountry Alliance, and buffer zones were made around each trailhead. These data points were transformed and entered into ArcGIS online in order to analyze the effect of each of the four factors on avalanche frequency. Reported avalanches were conglomerated and standardized using a spatial join to create slide zones. I found that zones with the highest rate of human interaction intersected the highest avalanche frequency, while elevation potentially factored into slide frequency. However, aspects seemed to have less of an association.

Introduction

In post pandemic years backcountry travel has skyrocketed, especially in high density areas of outdoor recreation such as the Central Wasatch (OnX). Overall estimates show winter backcountry travel doubling from the 2018/19 season to 2021/22, and high usage areas are expected to have maintained or even increased from 21/22 numbers in the last year (OnX). The increase in popularity of backcountry travel necessarily has increased travel in potential avalanche terrain, a rapidly growing area of research, but one in which very little is concretely known. While some aspects of travel through avalanche terrain are inherently unknown, increased effort has been applied to learn about snow science and avalanche tendencies to keep people safe in the backcountry.

The Wasatch Range in Utah is a mecca of both on and off resort skiing, and contains one of the highest avalanche risk roadways in the world — Little Cottonwood Canyon — which is 76% covered by frequent slide paths (UDOT). The frequency of slides is a relatively unique problem to this area, and a variety of factors must be judged, estimated, and acted upon to keep people safe. Similar frequently avalanching paths in Rogers Pass, British Columbia show a large variety of terrain and weather related factors are crucial indicators of naturally occurring slides. A 2017 study found the maximum snow water equivalent (SWE), and roughness to be the most important climatological factors in regards to avalanche frequency, with both increasing snow roughness and SWE resulting in more frequent slides (Smith, Mcclung, 2017). Additionally, slope angle and length of path were significantly correlated with avalanche frequency (Smith, Mcclung 2017). Most avalanche centers classify avalanche terrain as any slope over 30 degrees (AIARE) — lower angle slopes lack the gravity to separate the layers of snow to create an avalanche — which is what I will classify as avalanche terrain in this analysis.

However, this must be caveated by the fact that naturally triggered slides occur rarely, generally only during short time periods of both low snow stability and heavy precipitation. Instead it is estimated that almost 80% of avalanches are triggered by human activity in the backcountry (Mcclung, Grímsdóttir 2006). Therefore non-weather related causes are also an important area of study in avalanche science, especially when targeting research to increase safety of backcountry users. Quantitative analysis of human-induced avalanches in relation are typically difficult to obtain. Therefore, while avalanche courses such as an AIARE Level 1 have introduced the “human factor” as an equally important safety measure during backcountry travel, only a few studies conducted on heli-skiing operations have attempted to co-analyze risk based on both human factor and terrain features. One such study, which excluded non-skier related avalanches, ranked four different factors in terms of influence of avalanche frequency, finding snow stability to be most important followed by elevation, time of year, and aspect (in that order) (Mcclung, Grímsdóttir, 2006).

The applicability of these results to other locations are difficult to quantify. Specificity of terrain and weather has massive variability between locations, and human use, reporting, and snowfall are borderline impossible to normalize with current data. Therefore this report will aim to dig into the avalanche frequency by the four previously stated factors - elevation, aspect, season and predicted human interactions, in a smaller zone: the central Wasatch, designated as the Salt Lake avalanche area by the UAC, in order to add to the knowledge of avalanche terrain and risk assessment. The analysis is intended to provide a richer understanding of the risks and frequency of slide paths to avalanche, increasing awareness and knowledge of backcountry users and in turn hopefully providing a basis for more aware decision making.

Data

The Utah Avalanche Center (UAC) is one of the longest running and most respected research centers in the country, with a wealth of data from the past two decades (UAC). Avalanche data frequency acquisition was collected from the Utah Avalanche Center reports page as of February 16, 2023, and coordinates for reported avalanches were then converted to X, Y, points. Data from outside the Salt Lake City avalanche area, denoted by the UAC, was removed to narrow the scope of the study and increase editability of the data. The UAC avalanche reports also generally include elevation, aspect, slope angle, coordinates, time of year, and notes, although these are not professionally reported or required for every avalanche report. Major avalanche slide paths have been recorded and previously transformed into shapefiles by the Utah Department of Transportation for slides near human infrastructure. These slide zones were acquired via UDOT as a shapefile. In addition, the Utah Interstates shapefile UGRC. is used to provide context of road positions of SR-210, SR-190 (Little and Big Cottonwood Canyons), and Millcreek Canyon Road. A shapefile of winter backcountry trailheads off of SR-210 and SR-190 and multiple data tables tracking winter trailhead usage were provided by the Wasatch Backcountry Alliance in collaboration with the US Forest Service (USFS). All maps, databases and shapefiles are projected into NAD 12N which encompasses the state of Utah.

Methods

The main form of analysis and method of creating visuals was through ArcGIS with supporting work done on other ESRI software, namely ArcCatalog, as well as Microsoft Excel and Rstudio. All shapefiles were projected to NAD 12 N in either ArcCatalog or ArcMap before any analysis or other work was done.

The UAC offers an avalanche report page on their website that includes all professional and recreational avalanches, snow reports, and general observations. This page was sorted to include only reports of avalanches, and downloaded on February 16, 2023. Once downloaded, and avalanches outside of the Central Wasatch Range, denoted as “Salt Lake City” by the UAC, were removed to increase processing speed. All avalanche reports require the input of coordinates, which were converted to X,Y points following a procedure from Tufts Labs (Cite). Once transformed, the avalanche points were intersected with the Utah Avalanche Paths shapefile acquired from UDOT, and each point was given then attributes of the slide path (polygon), and only points that fell within slide paths were kept. The intersect was then renamed Avalanche_Intersect and a new factor (FID_count) was created by summing the slide path FID. This layer was then joined to the slide path polygons using a spatial join. Avalanche frequency was then classified by FID_count (reported avalanches inside each polygon) using graduated color symbology, broken by geometric interval into three breaks and normalized by shape area of the slide path polygon. The final layer was renamed Avalanche_Frequency_Final, and all subsequent analysis maps were built off a copy of this layer.

Aspect and elevation of slide paths were determined using information in the UDOT avalanche paths shapefiles, no additional aspect or elevation information was added. In order to create standardized aspect and elevation data, the spatial join was removed from a copy of the Avalanche_Frequency_Final layer. Aspect was determined using UDOT’s information, and any slide path that had a range of aspects was given the average aspect (ex: N-NW-W would be assigned a NW aspect). Elevation was standardized using criteria from the UAC. Starting zone elevation was reported in 37 slide paths, and a new factor was manually added, classifying below 8,000 ft as low, between 8,000 and 9,500 ft as medium, and over 9,500 ft as high elevation. Two copies of this layer were made, and definition queries were applied to both to remove extraneous polygons. The query for elevation used the following formula: Elevation1 = "Low" OR Elevation1= "Medium" OR Elevation1 = "High". Aspect was queried similarly, using: Aspect1 = "N" OR Aspect1 = "NW" OR Aspect1 = "S" OR Aspect1 = "SE" OR Aspect 1 = "SW" (other aspects were not queried for as they did not show up on any slide paths). Aspect and Elevation maps were both rejoined with the Avalanche_Intersect points to remove slide paths with no reported avalanches. A copy of the Avalanche_Frequency_Final layer was then intersected with the aspect and elevation layers to remove slide paths with no reported data. Frequency and Aspect and Frequency and Elevation were overlaid to create analysis maps.

Human usage was classified entirely from excel sheets and shapefiles provided by the Wasatch Backcountry Alliance. A winter trailhead usage table was cleaned using the following steps: first any trailhead that didn't have at least on year of continuous data (December 1 - May 1) was removed; second, average daily usage was averaged for every year of continuous data provided; third, trailhead names were changed to match abbreviations in the shapefile table to allow for a join to be performed. The WBA shapefile and table were joined and trailheads without continuous data were removed. A one mile buffer was made around the trailhead points to classify areas of high traffic, and trailheads were assigned low, medium, or high usage based on a three-tiered Jenks natural breaks classification. Two trailheads on either side of lower Big Cottonwood were then merged due to their close proximity. A definition query was applied to trailheads using the formula: Usage = "Low", and slide paths in proximity to those trailheads were determined using the formula: Select by Location → slide paths by trailheads → intersect within one mile (of trailheads). Frequency of all slide paths selected was collected, and the same process was repeated, with the definition query being cleared and changed to Usage = “Medium” and Usage = “High”.

Results

Aspect

There were a total of twenty two slide paths analyzed in Map 3, Aspect by Frequency. The twenty two paths were relatively evenly split between low, medium, and high frequency. Data showed directly south facing slopes to have a higher portion of slides, however that is hard to justify as significant due to the small sample size. In addition no particular aspect showed any proportionally higher number of high frequency slide paths. Directly south aspects were the only direction to report all three frequencies of slides, and held all the medium frequency slides analyzed by aspect.

Elevation

There were 37 slide paths analyzed by starting zone elevation, also known as the highest point of a slide path, frequently the initiation or trigger point of most avalanches. Importantly, no low elevation slides were included in the analysis due to a lack of data. Approximately 83% of all avalanche paths analyzed by elevation had a high elevation, or alpine, starting zone. Similarly, 81% of medium frequency slides and 85% of high frequency slide paths were found to be in high elevation zones. Low frequency slide paths also occurred more often at high elevations (69% at high elevation), although they were not as skewed by elevation as medium and high frequency paths.

Frequency by Aspect	N	S	SE	SW	Total
Low	0	5	2	1	8
Medium	0	7	0	0	7
High	1	2	2	2	7

Table 1. Avalanche frequency (left) by aspect (top) of slide path. Total represents the total number of slide paths in the frequency group that were analyzed. Data summarized based on Map 4 (Frequency by Aspect), and based on original data obtained from the UAC, and UDOT, as of February 2023.

Frequency by Elevation	Low	Medium	High	Total
Low	0	4	9	13
Medium	0	2	9	11
High	0	2	11	13

Table 2. Avalanche frequency (left) by Elevation (top) of slide path starting zone. Total represents the total number of slide paths in the frequency group that were analyzed. Data summarized based on Map 3 (Frequency by Aspect), and based on original data obtained from the UAC, and UDOT, as of February 2023.

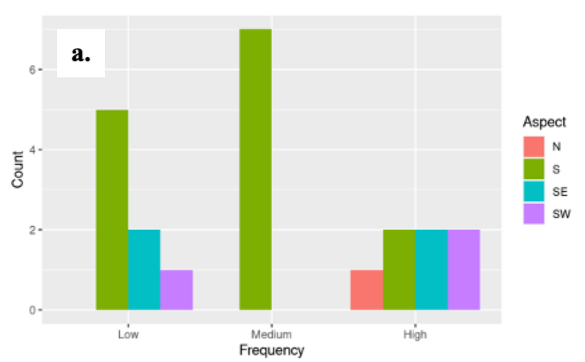
Human Usage

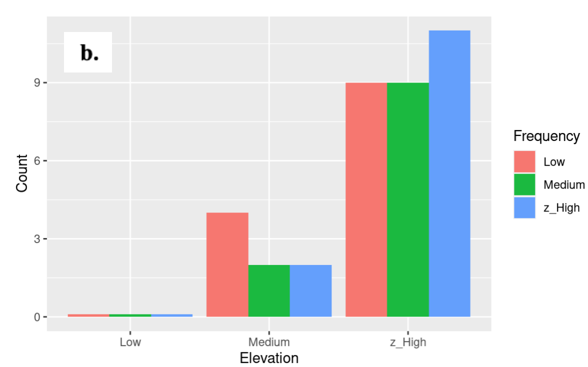
The analysis of the effect of human usage on slide frequency was the most extensive analysis, with 61 total slide paths falling within analysis zones, and all 145 final slide paths being included in the possible analysis. A total of just over 75% of slide paths in the analysis fell into high usage zones, with 10% in medium usage and 15% in low usage zones. While the total number of slide paths per usage zone could be significant, it could also be due to confounding variables. However, 91% of high frequency slide paths fell in high frequency usage zones, well over the 75% threshold. Both medium and low frequency slide paths occurred less than the null

Frequency by Usage	Low	Medium	High	Total
Low	4	2	14	20
Medium	5	3	21	29
High	0	1	11	12

Table 3. Frequency (left) of avalanche paths by human usage rating (top). Total represents the total number of slide paths in the frequency group that were analyzed. Data summarized based on Map 5 (Frequency by Human Usage), and based on original data obtained from the UAC, WBA, and UDOT, as of February 2023.

75% threshold in high usage areas. All three frequencies of slide paths occurred within 2% of the medium usage threshold of 10%, showing no significance of human usage on slide frequency. Low human usage areas did not coincide with any high frequency slide paths, with a slightly higher occurrence of medium frequency slide paths than low frequency.





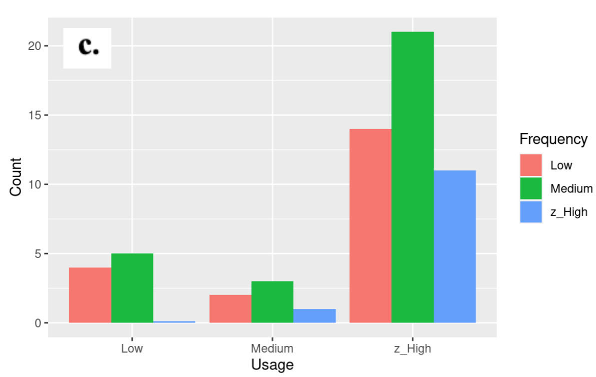
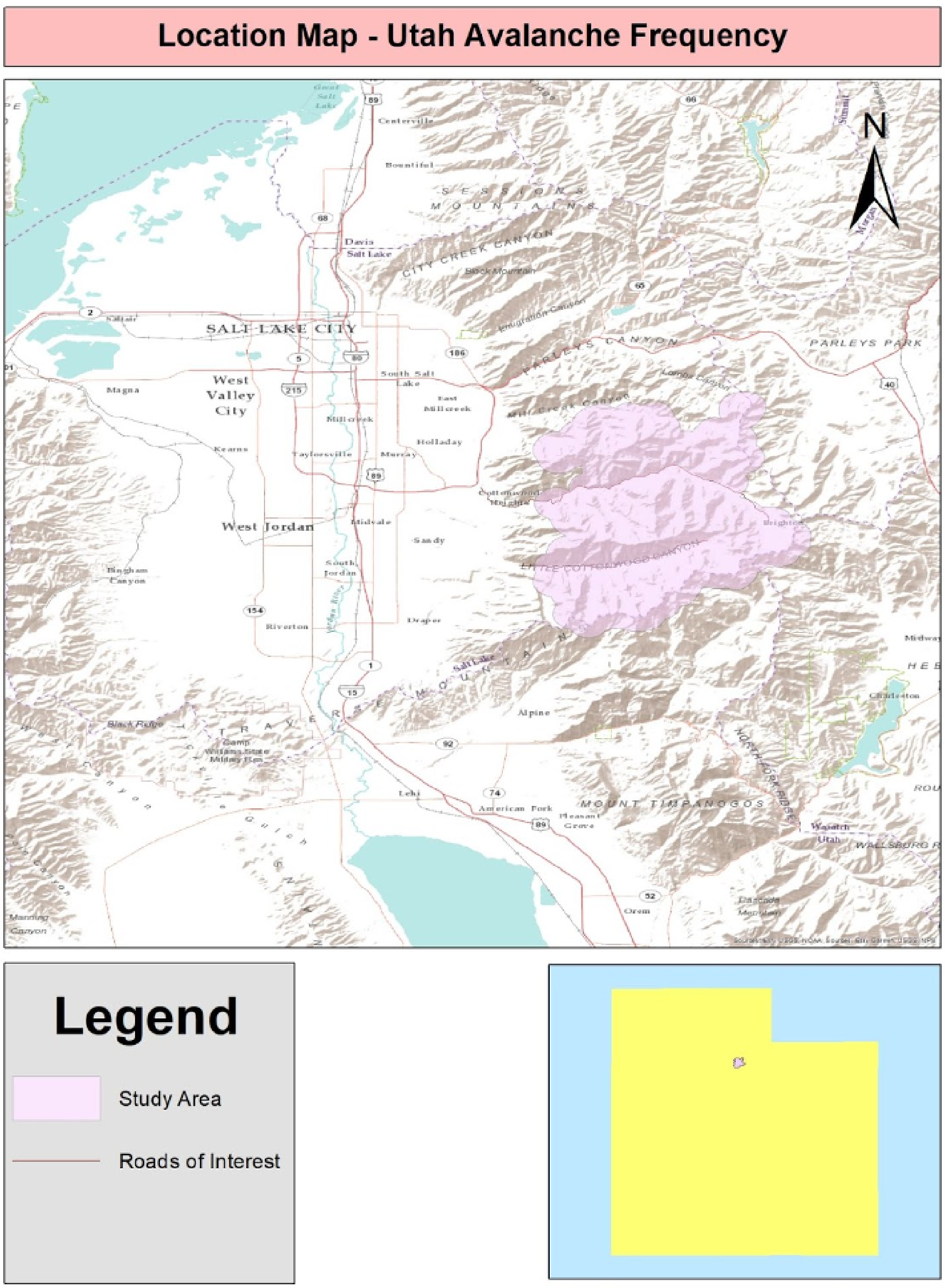


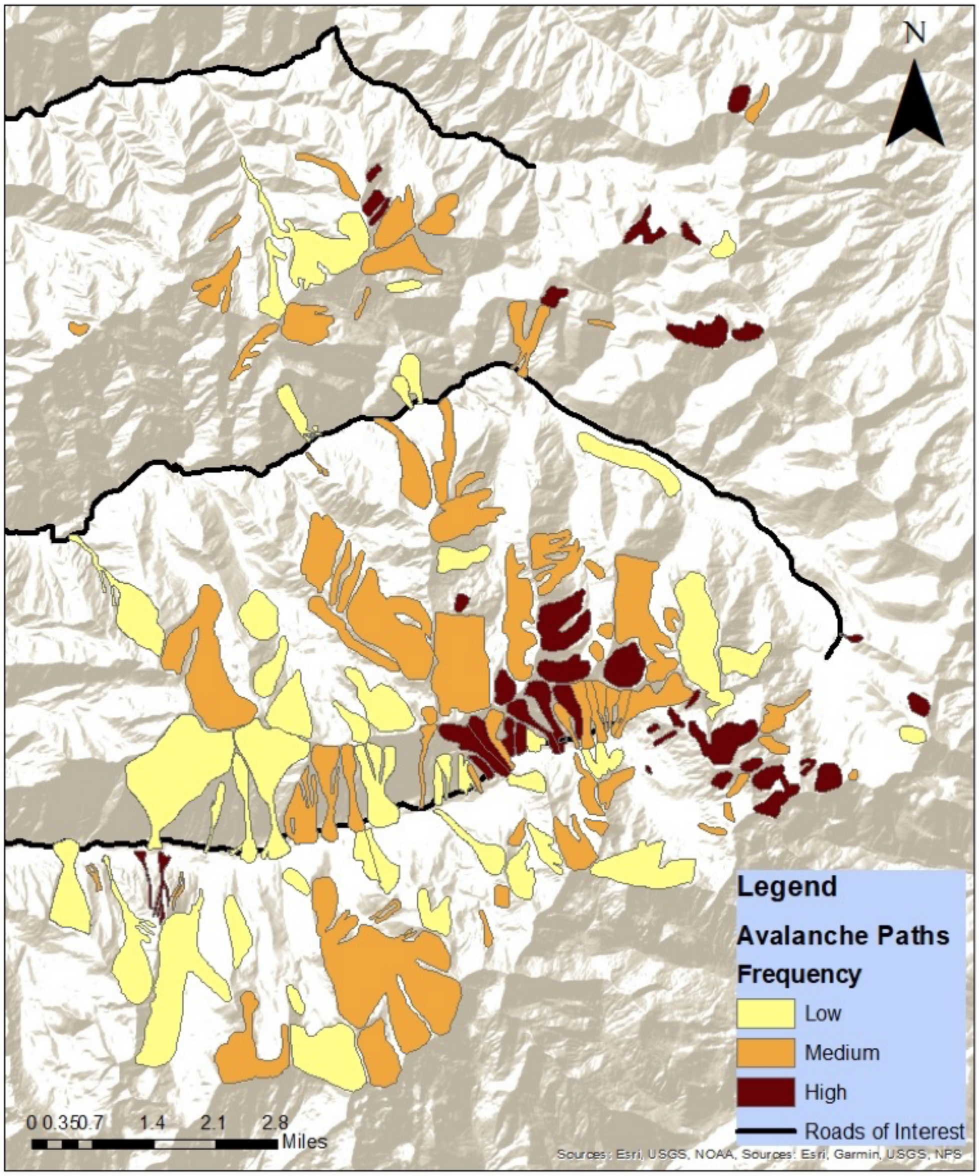
Figure 1 (a-c). Graphs of Avalanche frequency (labeled Frequency) by three factors, Aspect (a), Elevation (b), and Human Usage (c). Data taken from Tables 1-3.

Maps

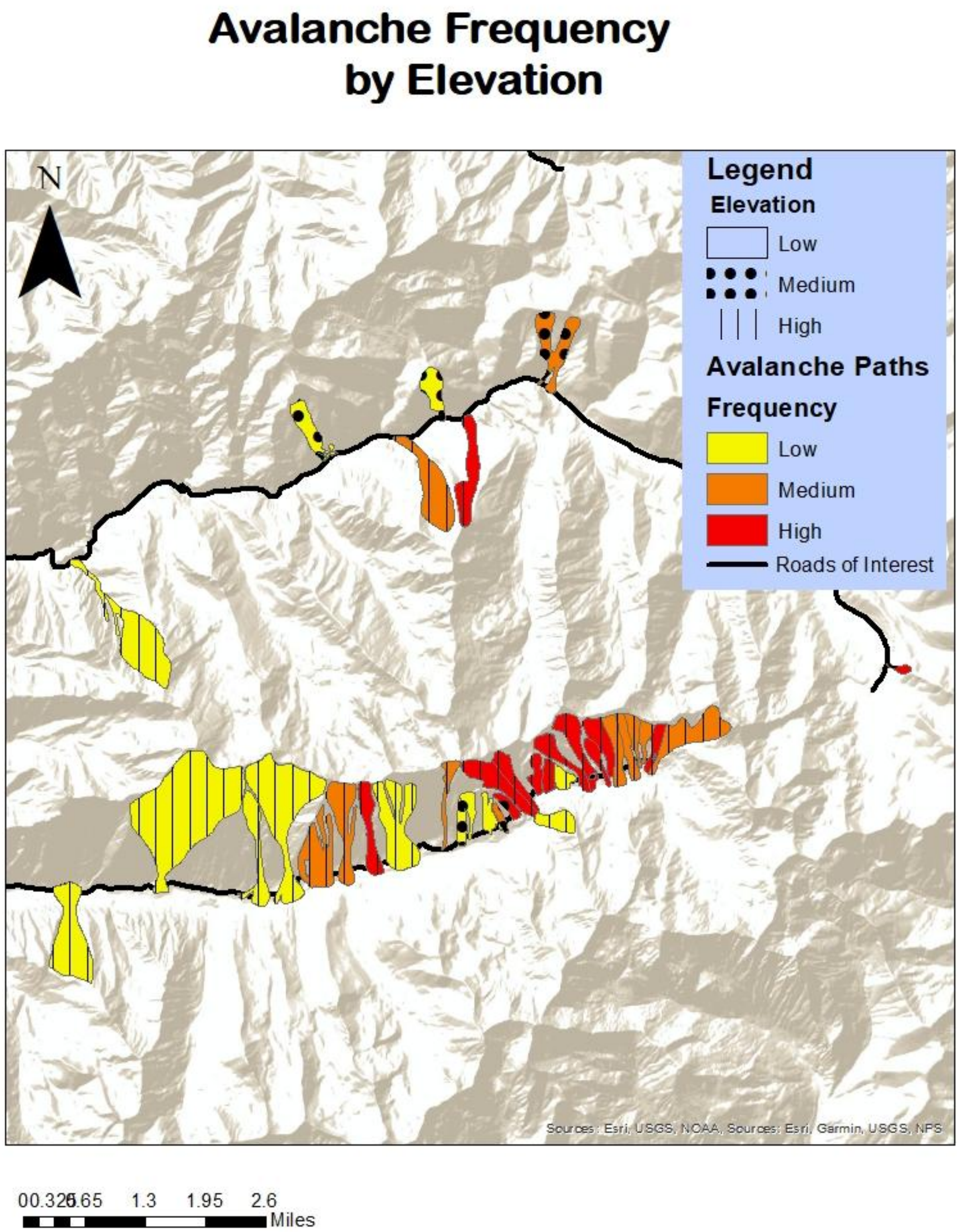
Map 1. A location map depicting the study area to contextualize the following analysis maps. The study area represents a buffer aggregating the approximate zone of all slide UDOT recognized slide paths in the Central Wasatch Range.



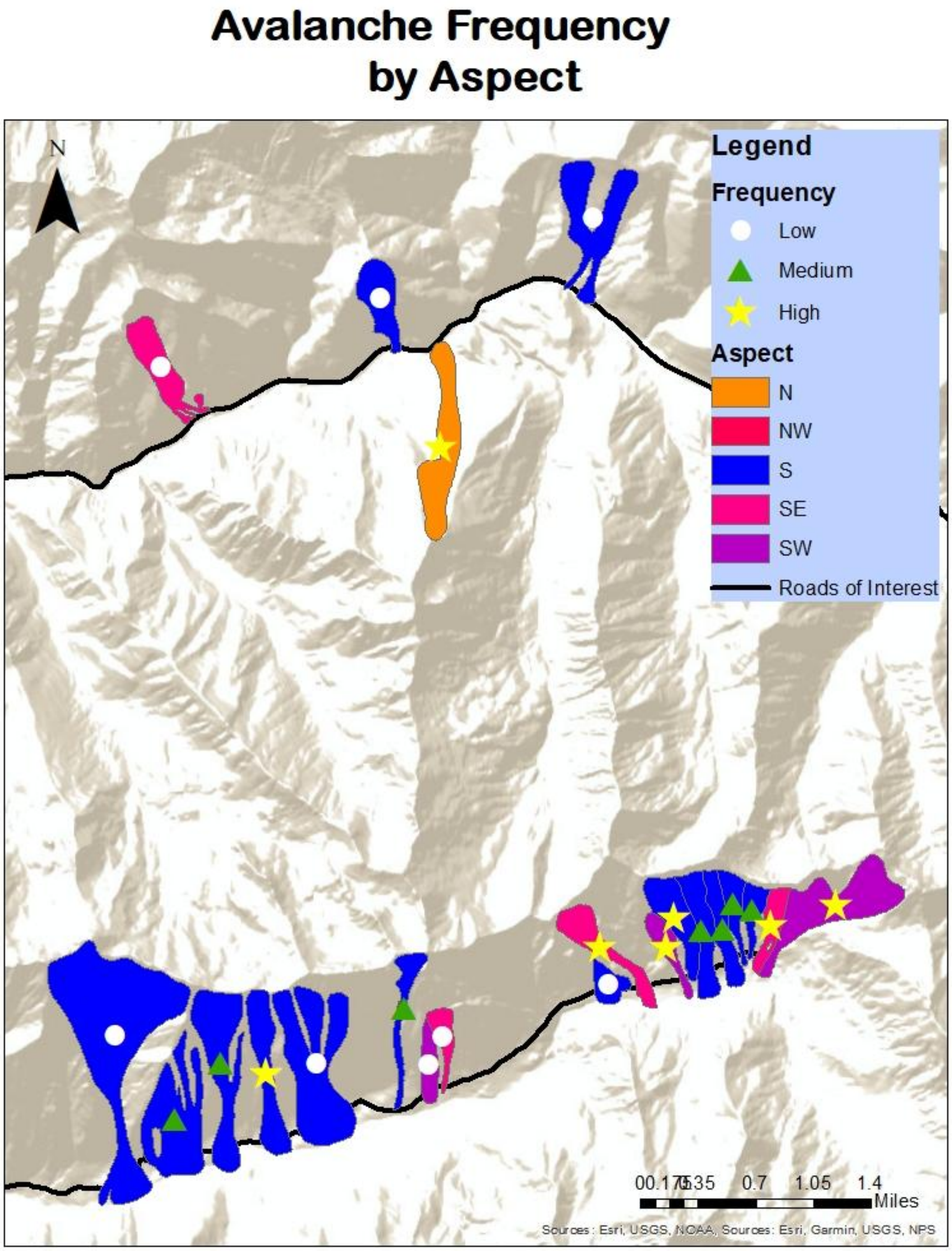
Avalanche Frequency



Map 2. Another contextualization map representing the initial analysis of slide path frequency. Colored areas of the choropleth map represent slide paths with at least one reported avalanche on the UAC report database (excluding reports without proper coordinate inputs) inside the designated study area.

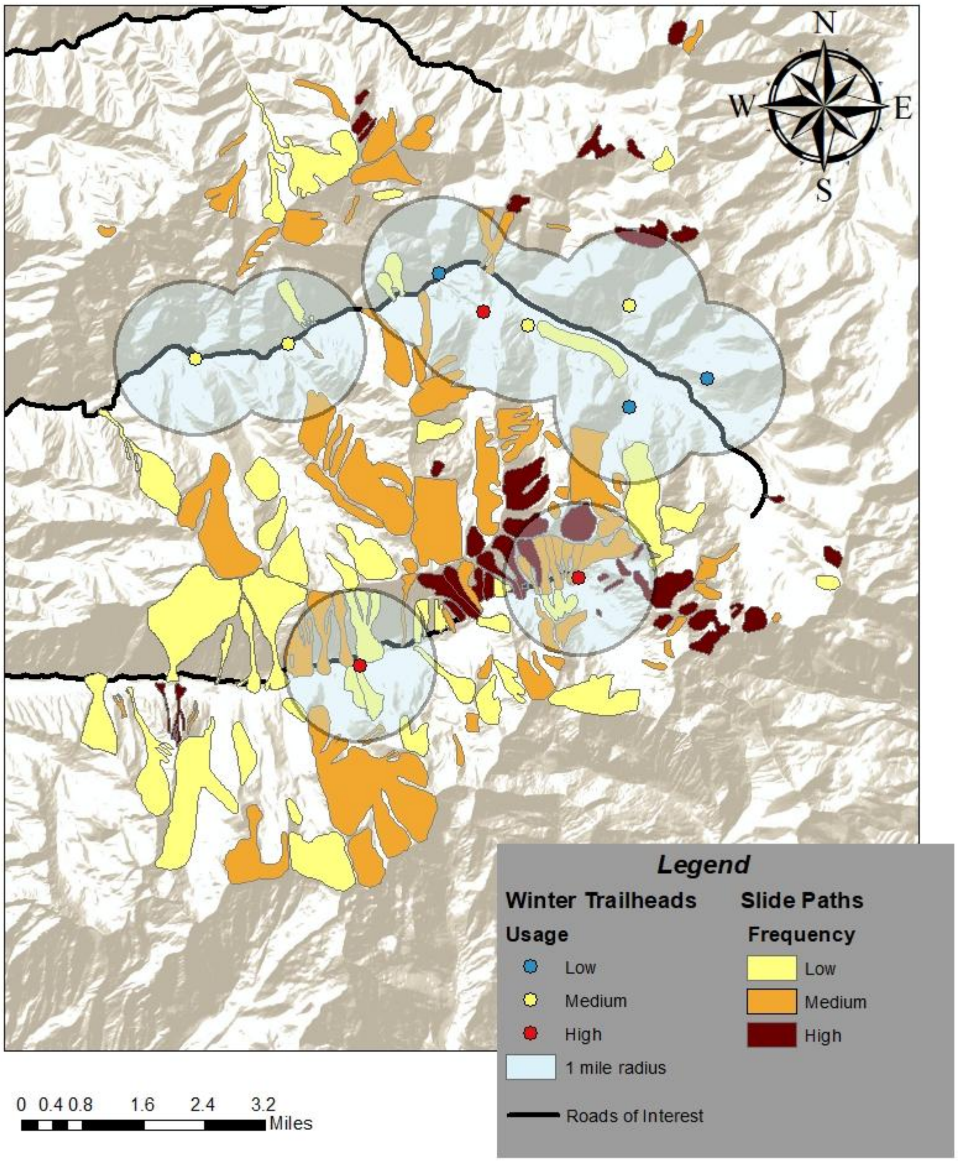


Map 3. Avalanche frequency (Map 2) by Elevation. Choropleth coloring represents frequency of slide paths, overlaid with elevation symbology. All slide paths without a prescribed elevation were removed to simplify the map.



Map 4. Avalanche frequency (Map 2) by Aspect. Choropleth coloring represents aspect, overlaid with frequency symbology. All slide paths without a prescribed aspect were removed to simplify the map.

Avalanche Frequency by Human Usage



Map 5. Avalanche frequency (Map 2) by Human Usage. Frequency map maintains the same coloring, overlain with trailheads split by usage levels (data from WBA). The 1 mile radius represents a buffer zone from each trailhead. Slide paths within the buffer were determined to be affected by human usage equal to trailhead status.

Conclusion and Implications

Increasing our understanding of avalanches is critical to increasing safety as numbers of winter backcountry users increase. With limited empirical research previously done, pulling from models and averages is a first step towards increasing the breadth of knowledge and literature on the subject. In addition, our current understanding of avalanches must come to terms with the rapid effects of climate change, which will likely increase severity and possibly frequency of slides due to a wetter climate with increasingly rough terrain (Strapazzon et al. 2021). While the effects of weather are relatively studied by avalanche forecasters throughout the world, exact differences in terrain, as well as the relative influence of the human factor, have been subject to less study. On average, avalanches result in 27 deaths per year in the United States (CAIC), with Utah reporting 1.5 deaths per year (UAC). In addition, infrastructure and roadways are at risk of avalanches in many areas, especially the Cottonwood Canyon of Salt Lake City.

This analysis showed a distinct correlation between human usage and avalanche frequency, with higher human usage correlating positively with increased frequency of nearby slide paths. There are two interpretations that can be easily extrapolated from this. First, similar to previous research, we see that human use could be a main factor in the triggering of avalanches, especially in highly populated and traveled areas such as the Central Wasatch. However, confounding variables likely also play some sort of role, although the significance of that role is still unclear. First, terrain choice for backcountry users, specifically skiers and snowboarders, could favor terrain more likely to avalanche, such as steep chutes and high elevation (Map 3). Secondly, observation bias was unaccounted for. Avalanche frequency was calculated based on reported data, and higher use areas would have had more eyes and likely more opportunity for avalanches to be seen and therefore reported to the UAC, while in lower usage areas natural avalanches could have gone unseen or be covered with new snow between travel.

Elevation analysis followed expected trends, based on previous avalanche knowledge and some empirical data, there was an expectation to see higher elevation starting zones correlate with higher frequency slide paths. It can be concluded that higher elevation zones are likely more dangerous areas than avalanche areas from a slide frequency perspective. This is likely due to increased snowfall that tends to be seen at higher elevation (NASA) (Smith, Mcclung, 2017). Prevailing aspects of avalanche paths showed little correlation with slide frequency. However, for both aspect and elevation two important sources of error must be understood. First, there was limited data which had previously quantified either of the variables, and therefore the small sample size could be misleading. In addition, the data that was available tended to favor slide paths that UDOT bombs regularly over the winter, which lead to a favoring of high elevation slide paths and south facing slopes (most north facing slopes in the central Wasatch fall under the authority of ski resorts). These factors could have skewed data, or led to the whole picture not being fully understood.

Future research should attempt to more thoroughly classify terrain features such as aspect and elevation to integrate all possible variables. In addition, it would be interesting to remove purposeful triggering of avalanches, such as roadway bombings, which are common on the south facing slide paths of Little Cottonwood Canyon, where a majority of the high frequency slide paths are shown to be, since the purposeful triggering of an avalanche is less indicative of a dangerous slide. Lastly, analysis of seasonal differences in frequency of slide paths, specifically analyzed by terrain features such as aspect and elevation. This would help predict danger even more specifically for both backcountry users and safety managers, in addition with other resources.

Bibliography

AIARE. (2023, February 2). *AIARE 1*. AIARE- American Institute for Avalanche Research and Education. Retrieved April 26, 2023, from https://avtraining.org/courses/aiare-1/

CAIC. (2023). *US accidents table: Colorado avalanche information center*. US Accidents Table | Colorado Avalanche Information Center. Retrieved April 26, 2023, from https://avalanche.state.co.us/accidents/us

Lerner, L., & Lerner, B. W. (2003). *Cold and Snow*. NASA. Retrieved April 26, 2023, from https://earthobservatory.nasa.gov/images/8349/cold-and-snow

London, A. (2023). *Wasatch Backcountry Alliance – protect the Central Wasatch*. Wasatch Backcountry Alliance – Protect the Central Wasatch. Retrieved April 26, 2023, from https://wasatchbackcountryalliance.org/

Mcclung, D. M., & Grímsdóttir, H. (2006). *Comparison of aspect of avalanches [p(as I |A s)] and usage of aspects* ... Research Gate. Retrieved April 11, 2023, from https://www.researchgate.net/figure/Comparison-of-aspect-of-avalanches-PAS-i-A-s-and-usage-of-aspects-PtAS-i_fig16_227274986

Parmenter, B. (2019). *Displaying latitude and longitude data adding XY data in arcgis*. Geocoding in ArcGIS. Retrieved April 16, 2023, from https://sites.tufts.edu/gis/files/2019/09/Displaying-Latitude-and-Longitude-Data-Adding-XY-Data-in-ArcGIS_10.7.1.pdf

Smith, M. J., & McClung, D. M. (2017, January 20). *Avalanche frequency and terrain characteristics at Rogers' pass, British Columbia, Canada: Journal of Glaciology*. Cambridge Core. Retrieved April 11, 2023, from https://www.cambridge.org/core/journals/journal-of-glaciology/article/avalanche-frequency-and-terrain-characteristics-at-rogers-pass-british-columbia-canada/F6D32F4B5A7C1438ED89C184DE18AFB5

Strapazzon, G., Schweizer, J., Chiambretti, I., Brodmann Maeder, M., Brugger, H., & Zafren, K. (2021, March 15). *Effects of climate change on avalanche accidents and survival*. Frontiers. Retrieved April 11, 2023, from https://www.frontiersin.org/articles/10.3389/fphys.2021.639433/full

Strickland, A. (2022, December 27). *The state of Avalanche Education and safety-survey by backcountry skiers*. onX Backcountry. Retrieved April 26, 2023, from https://www.onxmaps.com/backcountry/blog/avalanche-education-and-safety-survey

UAC. (2023). *Avalanches*. Avalanches - Utah Avalanche Center. Retrieved February 2023, from https://utahavalanchecenter.org/avalanches

UAC. (n.d.). *Who We Are*. Who we are - utah avalanche center. Retrieved April 26, 2023, from https://utahavalanchecenter.org/about/who-we-are

UDOT. (2023, January 6). *Cottonwood Canyons Avalanche Info - Udot Cottonwoods*. Cottonwood Canyons. Retrieved April 26, 2023, from https://cottonwoodcanyons.udot.utah.gov/avalanche-information/

UGRC. (2023). *Data*. Utah GIS Portal. Retrieved March 11, 2023, from https://gis.utah.gov/data/