UNDERSTANDING GLOBAL CROWD SOURCING DATA TO EXAMINE TRAVEL BEHAVIOR IN AVALANCHE TERRAIN

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ABSTRACT: This paper will present a subset of our results from our last three seasons (2013/14 to 2015/16) of global crowd sourced data collection to examine travel behavior data for people moving in avalanche terrain. Most previous studies of the human dimensions of decision making in avalanche terrain has focused on post-accident analysis using accident reports/interviews and the development of tools as decision forcing aids. We present an alternative method for understanding decision-making in avalanche terrain. Our project combines real-time GPS tracking via a smartphone application, with internet based surveys of backcountry skiers as a method to describe and quantify travel practices in concert with group decision-making dynamics, and demographic data of participants during daily excursions into winter backcountry. We present a subset of the results of more than 2000 unique trips by more than 500 individuals and groups.

Preliminary data analyses shows that individual experience level, group size and gender all influence the terrain used when standardized for regional avalanche danger rating. Furthermore, when only the regional danger rating is considered limited differences are seen in the slope angles used. Using these data we also examine the role of heuristic traps to assess their impact on terrain use. Our results provide the first analysis of coupled real-time GPS tracking of people moving in avalanche terrain combined with psychographic and demographic correlates. This research will lead to an improved understanding of real-time decision making in avalanche terrain.

KEYWORDS: Backcountry skiing, GPS tracking, Decision making, Avalanche terrain, Crowd-sourcing

1. INTRODUCTION & BACKGROUND

Natural hazards have primarily been viewed as phenomena of the geographical and biological domains and research has attempted to enhance the understanding of the physical system in an effort to decrease the incidence of accidents. Recently, here has been a shift towards a “more comprehensive human–environment perspective that also integrates societal and human aspects into the assessment and mitigation of natural hazards, placing considerably more emphasis on social science contributions” (Haegeli et al., 2010, p.186). Concurrently, much of the social science research in the field of natural hazards has focused on the societal vulnerability (i.e. macro economic costs) and the role of policy level intervention (i.e. planning and zoning laws) on minimizing exposure to, and increasing adaptive capacity to, natural hazards. For our proposed setting – potentially avalanche prone slopes, there is an asymmetric mix of research focusing on the physical object the activity is based around (i.e. snowpack stability assessment) evidenced by Harvey, et al. (2002) and Barbolini, et al. (2011) with less attention given to the human drivers of accidents and associated decision processes (i.e. flawed decision making, poor communication skills, lack of pre-trip planning). Our approach is focused on individuals and small groups where terrain complexity plays a initiating role in decision processes.

In terms of accident analysis, recent avalanche accidents in the USA suggest the terrain issue is important – patterns among multiple victim avalanche accidents suggest poor terrain choice contributed to a loss of life (e.g. Grand Teton NP, Wyoming: 2011 (2 caught, 2 fatalities); Stevens Pass, Washington: 2012 (5 caught, 3 fatalities), Loveland Pass, Colorado: 2013 (6 caught, 5 fatalities) (CAIC, 2016). The work of Atkins (2000) and McCammon (2002; 2004), represents an effort to understand the human factor in avalanche acci-
Hazardous terrain, when combined with complex geographical features, has a quantifiable effect on decision-making by small groups of people traveling or working under conditions of high risk/low probability catastrophic events in natural landscapes. We suggest that geographic constraints may be the primary decision making driver for such high stakes decisions and act as the instigating factor for decision making. This research will expand our understanding of how visual perceptions of terrain and geographical features influence decision making by small groups of people traveling or working under conditions of high risk/low probability catastrophic events in natural landscapes.

2. METHODS

Our methods have been summarized in Hendrikx and Johnson (2014) so will only be briefly presented here. An overview of the project can also be found on our project webpage at www.montana.edu/snowscience/tracks

To participate, participants complete a pre-season survey that describes their demographics (gender, age, education, employment status, marital status, children), skill level in several areas (other outdoor activities, years of skiing, expertise from beginner to expert), backcountry touring skills (terrain and snowpack assessment proficiency, avalanche education, transceiver proficiency) and personal decision making strategies. Next, they record GPS tracks via a smartphone application and submit it to the project email address tracks@montana.edu. Finally, an automated reply sends them an additional survey that queries their day’s traveling companions’ demographics, decision making routine, and several questions that test the decision process. On receipt, their tracks are converted into an ESRI shapefile and overlaid on a 10m DEM for analysis within a GIS (ESRI ArcGIS 10.2). Key terrain usage attributes relevant to assessing route safety and route options are extracted for each track.

Our surveys have undergone several iterations and appear to have a high level of face and test validity. Our smartphone GPS software is accurate to within the 3-15m range; adequate for our terrain analysis given that we will use a 10m digital elevation model (DEM). The analysis we present below include demographic descriptions of our respondent groups and terrain utilization as derived from the GPS tracks.

Our sampling is based on a modified snowball convenience strategy. We depend on exposure to the project via public talks, articles in the relevant press, notices on avalanche advisory sites, electronic listserves of associations and memberships, and word of mouth to solicit respondents for the pre season survey. We did this for the whole of North America and parts of Europe. An example of a sub-set of tracks submitted for the Teton Pass region of Wyoming over a 1 week period is shown in Figure 1.

![Figure 1: Example GPS tracks sourced from backcountry winter users in the Teton Pass area, Wyoming, USA, where tracks in red represent those recorded as self-assessed experts (as per our survey), and where tracks in blue represent those recorded as self-assessed intermediates.](image)

For analysis of the Likert scale and other survey responses for two independent samples (i.e. two groups) we used the Mann-Whitney U Test at the p < 0.05 level, and where there are multiple independent samples (i.e. two or more groups) we used the Kruskal-Wallis Test at the p < 0.05 level. For the terrain analysis, we propose that rather than focus on the entire population of data of slopes used by a given group, on a given day, that we should be more focused on the most extreme (or steepest) component of a day – i.e. the maximum, 95th, 99th and 100th percentiles of the slopes used, to show potential changes in travel behavior under varying groups and or conditions. These are also the most likely trigger points for avalanches, as these slopes are typically in the start zones.
3. RESULTS AND DISCUSSION

Given the large volume of data, and lack of complete automation of the terrain analysis, only a subset of our total data set is presented here. For brevity, we also only present a sub-set of our analysis.

3.1 Participant demographics

Hendrikx and Johnson (2014) presented preliminary data on the demographics of the sample population. Our additional data has not substantially changes this. An overwhelming majority of our respondents were still male (over 80%) and the modal age bracket was still 26-35 years old.

3.2 Participant experience

Similar to the demographic results presented in Hendrikx and Johnson (2014) the experience level have not substantially changed. We still see a slight majority of participants as “expert” backcountry travelers, and almost no “novice” backcountry travelers. This skewed sample may be because experienced skiers attend regional snow and avalanche workshops or engage BC related media at a higher rate and thereby became aware of our project.

3.3 Terrain use as a function of experience

In our earlier ISSW paper (Hendrikx and Johnson, 2014), we considered the difference between expert and intermediate BC travelers, and showed how aspects of their avalanche competency and decision making are significantly different. We will now also examine if these differences extend to how they utilize the terrain. Our key metric to define changes in terrain behavior for this analysis will be slope angles used, specifically the steepest slopes used on their trips (i.e. 99th, 95th and 90th percentiles).

In all cases, the statistical test, the Mann Whitney U test, shows that groups with the first skier listed as expert used, on average (i.e. the median), steeper slopes that those where the first skier was listed as an intermediate. This was evidenced (p < 0.05) for the 99th, 95th and 90th percentiles of slopes used, and shown for the 90th percentile in Figure 2.

3.4 Terrain use as a function of decision making

When we considered other decision making factors that we asked about as part of the daily post-trip survey, we note that questions that related to leadership and team dynamics made no statistically significant difference with respect to the steepest slopes skied by people. For example, examining the corresponding terrain attributes of different responses for the questions “Everyone shared observations freely” and “Did your group have a clear (i.e. designated) leader?” showed no difference. We thought that the leadership question in particular might show indications of shared decision making compared to autocratic decision making. The other four questions of “There were frequent terrain selection discussions”; “The group reassessed decisions throughout the day”; “I think group members accurately conveyed their observations to each other” and “The group was willing to make changes to the choice of route/objective?” showed the same, null result with respect to the steepest slopes used.

Furthermore, questions that related to travel practices (e.g. “As a group we cross potential avalanche paths one at a time”), method and frequency of snowpack observations (e.g. “How did you assess the snowpack?”), and group commitment (e.g. “Generally speaking, how committed was your group to the day's goal?”), showed the same, null result with respect to the steepest slopes used.

When we consider the issue of group familiarity with an area, we see what at first may be a surprising result (Figure 3). Not all participants provided a response to this question, so these results
are a subset of the above data. The steepest slopes used (as measured by the 99th percentile) are higher for those areas that groups have “Very low” familiarity with. This is statistically significant (at the $p < 0.05$ level) for the 100th, 99th, and 95th percentiles of slopes used. One might have expected that areas more familiar to a group (i.e. Very High) would be the areas where the limits would be pushed and the steepest slope angles used would be higher. However, on closer examination of these results, we can understand the reasons for these data. When we consider the avalanche danger ratings for the days with “Very low” familiarity we see that these days are comprised of low (20%) moderate (50%) and considerable (30%), compared with the days with “very high” familiarity which were comprised of moderate (54%), considerable (38%) and high (8%). This suggests that the avalanche danger rating influences the use of the familiar vs unfamiliar terrain, such that when the hazard is higher, more familiar and lower angled terrain is used. This is also in contrast to the data presented by McCammon (2004) showing the role of familiar terrain in avalanche fatalities. These opposing results are not entirely unexpected as we are collecting data on non-fatality trips, which by in large, demonstrate sound decision making practices.

Fig 3: 99th percentile slope angles used by groups, as grouped by familiarity

3.5 Terrain use as a function of the group size

Another group factor of interest, which may influence decision making and resulting terrain use is the size and gender of the group.

Solo travel, while widely regarded as inappropriate behavior in avalanche terrain, does occur. However, until now the extent to which this happens, and the terrain that is used by solo travelers was merely speculation. Based on the results from our survey we observe that solo travel is fairly common, with more than 26% of all reported trips involving solo travel. The vast majority of these people were male, with only 6% being female. Of the solo tracks analyzed, almost half (47%) included traveling on slopes greater than or equal to 30°. Interestingly, all of these trips by solo travelers including terrain steeper than or equal to 30° were completed only by males, which described themselves as experts (and one as intermediate). No solo female travelers were on slopes greater than 30. In part this may also reflect the relatively smaller sample of females in our survey data. These solo trips were conducted mainly during periods of moderate avalanche danger (65%) and occasionally under considerable (26%) and low (4%) avalanche danger. The remaining tracks (5%) were under conditions of no posted avalanche hazard.

Groups of two travelers were the most common travel group size with 42% of all reported trips involving two members. Groups comprised of solely men were the dominant group (69%), while groups with one male and one female (27%) and two females made up the remainder (4%). These groups travelled under a range of avalanche conditions, but as with the solo traveler, groups comprised of only females tended to stay on lower angled slopes, when the 99th percentile of their slopes were considered. Groups comprised solely of men, while not exhibiting a statistical significant difference in the median steepest slopes used (as expressed by the 99th percentile of slopes), their range showed much steeper slopes being used.

Larger groups with more than 2 people, made up increasingly smaller components of our sample, with 3 members representing 13%, 4 members representing 10%, 5 members representing 5%, and 6 or more members representing 3% of all of the trips submitted. Larger groups tended to be hut trips. Similar to our results for solo and 2 person groups, the majority of the 3 and 4 member groups were made up of men, with only a few mixed and female only groups. When we consider the steepest slopes (99th percentile) by these groups, as divided by size we observed that there are no meaningful differences between any of the groups.

3.6 Terrain use as a function of the avalanche forecast

Our key metric to define changes in terrain behavior for this analysis will be slope angles used. When we plot the steepest slope angles used (as
represented by the 99th, 95th and 90th percentile) (Figure 4), grouped by avalanche danger rating, we notice that there is a statistically significant difference between those used under low danger ratings, compared to moderate and considerable (for the 100th, 99th and 95th percentiles). There is no statistically meaningful difference between moderate, considerable and high for any of the percentiles considered.

These results suggest that on average, the steepest slopes used are under low hazard conditions, and that the differences between the steepest slope angles used under other danger ratings are minimal. However, it is worth noting the large range for moderate hazard days, including the use of very steep slopes over 60°. These very steep slopes likely represent small cliff drops that when averaged on by a 10m DEM are represented by these high slope angels.

![Fig 4: 99th percentile slope angles used by groups, as grouped by avalanche danger rating. Low to the left, High to the right.](image)

When we consider these results, we need to remember that slope angle alone is only one metric to express terrain use with respect to terrain management and decision making. Examination of the terrain use by a single expert provides additional sight into this issue (Figure 5). Here we see that the median slope angle used for days with a considerable hazard were actually higher, than those used for low hazard days (Figure 5).

This might seem counter intuitive when considered in isolation, but when considered alongside the aspects used, we can start to see the reasons for this (Figure 4). The aspect data clearly shows that on low hazard days, groups travel on one primary aspect and half their time was on aspects between NE and SW. However on days with considerable hazard, their use of terrain was much more confined to between the ENE and ESE aspects. During the period of time and the region in which these tracks were collected, these aspects were the ones that were typically less loaded due to cross stripping from northerly winds. This clearly demonstrates that while slope angles, when grouped, provide some insight, a more detailed analysis of individual users terrain metrics can provide additional insights.

![Figure 5: The relationship between the posted avalanche danger (Low Vs Considerable) rating for the days of the track (x axis) and slope angle (Top) and Aspect (bottom) in ° from the GPS track (y axis). Box-plots show the median, the 25th and 75th percentile and maximum range shown.](image)

4. DISCUSSION

The implications of these results are that for the first time, we have a complete view of the demographics, psychographics and terrain usage by a cohort of BC travelers under a range of group, experience, and hazard conditions. These data, as a cohesive and combined set, have until now not been available. These data, while still presenting some challenges with respect to the isolation of
key driving variables, provide some insight into real time decision making and the resulting terrain usage as described by the steepest slopes used.

Based on the analysis of our pre-season survey, we can describe a typical participant as a male, aged 26-35, has a bachelor’s degree, is employed full time working 40 or more hours per week, can be either married or never married, has no children, and participated in several outdoor sports with hiking, downhill skiing, camping and mountain biking, trail running and rock climbing being done by 50% or more of the participants. Comparison of these results to the wider population of BC travelers is problematic, due to limited data on this community. However, these data to align to the results of Procter et al., (2013) who collected data on recreational skiers, and Johnson et al., (2016) who collected data on avalanche professionals.

Secondly, given the work by McCammon (2004) which suggested that avalanche education and overall proficiency might increase the likelihood of an avalanche fatality, we focused on the self-assessed BC skills of the participant. We showed that in our data set, for both the number of years of skiing and technical difficulty of ski terrain the difference between intermediate and expert groups were statistically significant. Our data shows that expert BC travelers will likely expose themselves to more severe terrain, but we make no statement about the resulting likelihood of avalanche fatalities by this group. However, when expert BC travelers without incident, are a self-selected sample, which likely means that the steepest slopes are viewed within a more defined geographic area and only a few degrees of freedom need to be considered (e.g. group / hazard level), so that an examination of how different groups use the same terrain within a more limited area can be completed. Despite these limitations from grouping a single terrain metric, some general trends can, and still are observed.

A limitation of the methods presented here are that we have only considered the actual slopes used, rather than the slopes above, or adjacent to a track (e.g. travel on low angled slopes below large avalanche paths in the runout zone in high hazard conditions are not necessarily safer than travel in the steeper start zones). Analysis using a more detailed Avalanche Terrain Exposure Scale (Stathem et al., 2006) may better account for these differences. There are also some data limitations as expressed through the smoothing of terrain features smaller than the mean grid size. For the work presented here we used a commonly available 10m DEM, but for other applications or more limited geographic areas higher resolution DEMs (e.g. 1m LiDAR) might be more appropriate. It could be that significant avalanche features the skier copes with are <10m in size such as small terrain traps, rollovers, etc, and these are lost in smoothing. Furthermore, our sample of participants are a self-selected sample, which likely means that we have the more engaged, and aware BC travelers represented. This has implications for our scope of reference, suggesting that our results may not be entirely representative of the wider BC community, and may display decision making towards the safer / more conservative end of the spectrum (i.e. a “longevity” heuristic?).

Despite these limitations, we consider that this approach has provided valuable additional insight.
into decision making in complex terrain by a cohort of BC travelers under a range of group, experience, and hazard conditions.

5. CONCLUSIONS
We have presented the results from a sub-set of our participants that submitted data to our project over the period 2013/14 to 2015/16. We successfully combined GPS tracking with online surveys on multiple user platforms in an effective method for tracking movement, ascertaining decision points, determining terrain usage, and hazard avoidance strategies for small groups of winter backcountry travelers.

Following McCammon’s (2002, 2004) identification of potential heuristics traps as contributors to avalanche accidents, we are able to review and test for several of his assertions in our non-fatality dataset. We find evidence for several including the familiarity heuristic, and contrary evidence for others including the group size, demographics, and commitment heuristics. Where we do find evidence of the familiarity heuristic we find the opposite dynamic of that presented by McCammon (2002; 2004) from his fatality database.

The primary research problem for those who study avalanche and other similar accidents is the difficulty of simultaneously tracking both the terrain usage and decision making processes of small groups. Our methods lend considerable investigative power to that problem and, our results show that indeed significant differences exist among winter backcountry traveler demographics. Ongoing data analysis is likely to yield further pertinent outcomes in a future manuscript.

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