Quantitative examination of terrain perception and its
effect on ski run choices in expert heli-ski guides

by

Brendan Wakefield

B.A. (Psychology), University of California Santa Cruz, 2011

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Approval

Name: Brendan Wakefield
Degree: Master of Resource Management
Report Number: 733
Title: Quantitative examination of terrain perception and its effect on ski run choices in expert heli-ski guides
Examing Committee: Chair: Henry Finn
MRM Candidate
Pascal Haegeli, Ph.D.
Senior Supervisor
Assistant Professor
Patrick Mair, Ph.D.
Supervisor
Senior Lecturer in Statistics
Department of Psychology
Harvard University

Date Defended/Approved: August 12, 2019
Ethics Statement

The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

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Abstract

Terrain selection is the primary tool for managing avalanche risk during backcountry travel. While some research has examined revealed preferences in professional ski guides to better understand terrain-use choices, the exclusive focus on physical terrain characteristics pertaining to avalanche hazard has offered an incomplete perspective. I present a new framework that comprehensively captures all decision-relevant terrain characteristics and links these features to decision-making in heli-ski guides. Using survey data from two operations, I employed ordinal logistic regression models to quantitatively describe the relationship between specific terrain features and guide perceptions of accessibility, skiing experience, hazard potential, and “guideability.” A Poisson regression model linking these perceptions to terrain use at one operation clearly illustrates how guide decisions are trade-offs between hazards and operational benefits. The framework provides researchers interested in terrain preferences with a structured approach to describe terrain more completely, and it offers practical benefits to heli-ski operations and guides.

Keywords: Perception; Decision-making; Avalanche terrain; Terrain characterization; Ordinal logistic model; Terrain selection
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<tr>
<td>ACMG</td>
<td>Association of Canadian Mountain Guides</td>
</tr>
<tr>
<td>AIC</td>
<td>Akaike Information Criterion</td>
</tr>
<tr>
<td>ATES</td>
<td>Avalanche Terrain Exposure Scale</td>
</tr>
<tr>
<td>BIC</td>
<td>Bayesian Information Criterion</td>
</tr>
<tr>
<td>CMAH</td>
<td>Conceptual Model of Avalanche Hazard</td>
</tr>
<tr>
<td>CMH</td>
<td>Canadian Mountain Holidays (e.g., CMH Galena)</td>
</tr>
<tr>
<td>DEM</td>
<td>Digital Elevation Model</td>
</tr>
<tr>
<td>IFMGA</td>
<td>International Federation of Mountain Guides Associations</td>
</tr>
<tr>
<td>NEH</td>
<td>Northern Escape Heli-Skiing</td>
</tr>
<tr>
<td>OH</td>
<td>Overhead (e.g., OH hazard)</td>
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<tr>
<td>OLR</td>
<td>Ordinal Logistic Regression</td>
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<tr>
<td>OR</td>
<td>Odds Ratio</td>
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<tr>
<td>RE</td>
<td>Random Effect</td>
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<tr>
<td>SARP</td>
<td>SFU Avalanche Research Program</td>
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<tr>
<td>SD</td>
<td>Standard Deviation</td>
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<td>SE</td>
<td>Standard Error</td>
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Chapter 1.

Introduction

The majestic mountains of western Canada offer an allure that many backcountry enthusiasts find irresistible in winter. The backcountry offers opportunities for untracked powder, and exciting mountain landscapes draw individuals interested in skiing, snowboarding, ice climbing, snowmobiling, and other winter activities. However, the benefits of this pristine and uncontrolled environment are not without risk. Snow avalanches are a well-known threat among backcountry travelers, and over the last ten winters, 106 individuals perished in avalanches while recreating in the backcountry of Western Canada (Avalanche Canada, n.d.). These fatalities included 45 mountain snowmobilers, 39 backcountry skiers, 11 snowshoers or hikers, and 11 individuals pursuing other winter backcountry activities. Since avalanche risk is composed of existing avalanche hazard and the exposure to the consequences should an avalanche release (McClung and Schaerer, 2006; Statham et al., 2018), the primary tool for effective avalanche risk mitigation in the backcountry is terrain-selection: choosing when and where to expose oneself to certain types of terrain in response to the nature of a particular day’s avalanche problem type, destructive size, and likelihood of triggering (Association of Canadian Mountain Guides, 1999; Statham et al., 2018).

Since making meaningful terrain choices requires considerable training and experience, terrain guidance tools can play a constructive role in improving the way backcountry travelers choose to match types of terrain to any given avalanche hazard situation. The Avalanche Terrain Exposure Scale (ATES; Statham et al., 2006) devised terrain classifications based on physical terrain characteristics to help recreationists more accurately assess the terrain of their intended backcountry trips (Figure 1). The system has been in use at recreational trail heads to alert travelers of the types of terrain they may encounter in that area (Statham et al., 2006). While the ATES system is an important step towards breaking terrain down into more meaningful categories, it is a static description of the terrain and does not provide explicit guidance about what type of terrain is appropriate under different types of avalanche conditions. The trip planning tool included in the Avaluator V2.0 (Haegeli, 2010) closes this gap by combining the ATES
rating of an intended backcountry trip with the predicted avalanche danger ratings. The Avaluator V2.0 provides recreationists with guidance on the amount of training, expertise, and caution required to manage the risk from avalanches under the expected conditions in a meaningful way (see https://www.avalanche.ca/planning/trip-planner for online implementation). However, effective terrain management is much more nuanced than the approach implemented in the Avaluator V2.0. As outlined in the description of the Conceptual Model of Avalanche Hazard (CMAH; Statham et al., 2018), different types of avalanches require different methodological approaches for using terrain that minimize a traveller’s exposure to avalanches based on their type, spatial distribution, and sensitivity to triggering. Selecting terrain that appropriately manages wind slabs, for example, is different from terrain that is ideal for avoiding excessive exposure to deep persistent slabs.

![Avalanche Terrain Exposure Scale (ATES) classifications overlaid on a topographic map with identified avalanche paths and trails (source: https://www.avalanche.ca/planning/trip-planner).](image)

**Figure 1** Avalanche Terrain Exposure Scale (ATES) classifications overlaid on a topographic map with identified avalanche paths and trails (source: https://www.avalanche.ca/planning/trip-planner).

One potential approach for developing more advanced terrain guidance tools is to systematically examine the terrain choices that professional guides make as a result of their deep knowledge and expertise. Western Canada is well-known for its mechanized skiing industry where professional guides use the assistance of helicopters and snow cats to transport guests to remote mountain locations and provide safe and exciting skiing on the way down. Since its inception in 1964 (Donahue, 2012), this
industry has grown to account for approximately 118,000 skier days per year and generates gross annual revenues of more than $180 million (Helicat Canada, 2019). Decades of practical experience have resulted in sophisticated operating procedures and rich community knowledge regarding what type of terrain is appropriate in different types of conditions. Israelson (2015) describes this process in mechanized guiding as a series of filters; each morning, the guiding team gathers to determine which runs within their available terrain will be “open” based on the avalanche hazard forecast for that day and their operational goals. The resulting “run list” represents a selection of runs that have been deemed safe for guiding and the team is considering for use in circuits on that day. “Lead guides” (more experienced guides responsible for deciding which runs a helicopter and its groups will visit) then work to determine an appropriate circuit of runs based on which runs will be most appropriate for their guests’ interests and will best serve the economic needs of the operation. Each helicopter will serve one or more groups but operates under the instruction of the lead guide. Guides of each group then determine the particular lines that will be skied within each run after arriving and assessing the small-scale terrain characteristics, snowpack observations, and local weather.

There is evidence that guides have developed intuitive tools to assist their decisions when coping with their uncertain and multi-faceted operational environments (Atkins, 2014; Haegeli and Atkins, 2010, 2016). This is reinforced by reflections from avalanche experts (Adams, 2005; Kay, 2016; McCammon, 2001; McClung, 2002) who highlight that quick decision-making in consequential environments is heavily influenced by subconscious factors. In experts, intuitive pattern-recognition stemming from extensive practical experience is encoded and retrieved quickly to aid choices under pressure and time constraints (Kahneman, 2011; Klein, 2015). This tacit terrain expertise offers a rich body of knowledge for better understanding the decision-making process and what constitutes effective terrain choices in avalanche terrain.

To take advantage of this extensive body of terrain knowledge, there is a growing body of research examining terrain choices in mechanized skiing in an effort to capture the terrain expertise of guides. This research has used run list data and GPS tracking as explicit representations of guides' terrain preferences at different scales, which has revealed that guide behavior depends on a day’s avalanche hazard situation and the nature of the terrain they choose to ski as described by physical terrain attributes (e.g.,
such as slope steepness, aspect, elevation, and forest density among others). Hendrikkx et al. (2016), for example, used handheld GPS units to record terrain preferences for 18 days of heli-ski guiding in Alaska. While they did not find statistically significant relationships between the average slope incline of the tracked ski runs and avalanche hazard conditions, their analysis did reveal the expected negative relationship between slope incline and avalanche hazard when more extreme summary statistics (i.e. the 90th, 95th and 100th percentiles) were considered. Using a much larger dataset of tracked heli-ski runs, Thumlert and Haegeli (2018) found that guides choose lines with less exposure to avalanche hazard on days with elevated hazard ratings and “open up” to more severe terrain when the hazard is lower. Similarly, Sharp et al. (2018) found that guides will expose themselves to potential avalanche release areas less often when the current hazard is higher.

While these studies offer an excellent starting point to identify relationships between environmental conditions and terrain decisions, a major shortcoming of these examinations is they only account for terrain characteristics pertaining to hazard and exposure. Whereas avalanche hazard is the primary factor driving the terrain selection in mechanized skiing, guides must also consider a complex suite of operational factors and guest characteristics, such as weather and flying conditions, flight economics, skiing quality, group sizes, guest preferences, and skiing abilities. Since the objective of professional guiding is to maximize the quality of the guest experience while operating within an appropriate safety margin (Association of Canadian Mountain Guides, 1999), analyses that only take into account ski run characteristics that relate to avalanche hazard are inherently incomplete. While guides certainly must avoid hazards, they also need to consider benefits of using terrain as well as physical barriers of access. A guide’s choice to ski a particular run or line therefore reflects a balance between the motivating factors that make it desirable for skiing and the adverse deterrents, such as those associated with avalanche hazard (Israelson, 2015). An illustration of this balance is the concept of the operational risk band (ORB) introduced by McClung (2002), which states that the risk associated with providing guests with a high-quality skiing experience needs to stay between two limits; excessive conservatism (i.e., too little risk) resulting in missed skiing opportunities, and too much risk leading to serious accidents. The presence of the lower limit highlights the difference between pure risk assessment and
management (such as in avalanche forecasting) and what mechanized operations are trying to achieve.

A more complete understanding of the factors driving decisions is necessary to make meaningful sense of terrain choice patterns in guides and properly isolate the effect of avalanche hazard. To explain patterns observed in run list ratings at two mechanized skiing operations, Sterchi and Haegeli (2019) recently introduced a comprehensive ski run characterization that includes information on all factors relevant to terrain choices. While the factors included in their characterization offer a meaningful starting point, the authors did not formalize their approach and did not perform an in-depth exploration of these characterizations. The objective of this research project is to expand on the ideas presented by Sterchi and Haegeli (2019) and present a comprehensive framework for characterizing the nature of ski runs more fully. This terrain characterization framework is composed of decision-relevant variables that describe both physical features as well as subjective perceptions of the overall nature of terrain. In this thesis, I use data from a survey built around the terrain characterization framework to quantitatively explore how the physical features influence terrain perceptions in guides, and I statistically link these overall perceptions to ski run use to quantify the relationships between the main themes that affect guides’ terrain choices. These quantitative relationships both test the validity of the terrain characterization framework (meaningful relationships imply an effective framework) and describe guide perceptions and their influence on their behavior.
Chapter 2.

Data and Methods

Addressing my research question required a comprehensive dataset of ski run characterizations and associated use frequencies. In this section, I describe my approach for collecting relevant data in detail and how I used two types of regression models to explore the relationships among terrain characteristics, guide perceptions, and terrain-use data.

The entire process for this research began with a new terrain characterization framework that identifies terrain features relevant to guiding and allows for data collection on the terrain variables that influence decision-making. The framework was the foundation for an online survey I used to collect guide assessments of skiing terrain in their tenure region. The survey asked questions regarding objective assessments of physical terrain characteristics as well as their subjective terrain perceptions. This allowed me to link physical terrain characteristics as predictor variables with subjective perceptions as response variables using ordinal logistic regression (OLR) models. The results of these models describe the relationships between terrain characteristics and guide perceptions. Finally, I combined the perception variables with line characteristics (Operational role(s), and Distance from lodge) as predictor variables in a behavioral model, which used counts of Line use as the response variable to explore how guide perceptions influence their behavior. An outline for my research strategy is shown in Figure 2.
The online survey gathered guide assessments, which were used to generate OLR models of four guide perception variables. The response variables of the OLR models were combined with two types of run characteristics to become predictor variables for the Poisson regression behavioral model.

2.1. Ski Terrain Characterization Framework

Providing insight into guiding decisions requires a comprehensive method for describing the essence of skiing terrain that goes beyond hazard and includes all relevant factors. I participated with a research team, which consisted of both researchers at the SFU Avalanche Research Program (SARP; Pascal Haegeli and Reto Sterchi) and senior guides with many years of experience in the mechanized skiing industry (Clair Israelson of Northern Escape Helicopters (NEH) and Roger Atkins of Canadian Mountain Holidays (CMH)), to collaboratively develop a novel, comprehensive framework that allows guides to describe the nature of ski runs in a way that offers both meaningful insight for fellow guides and useful data for research. The goal of the framework was to build on terminology that has been used in the guiding community for decades (e.g., “friendliness”, “guideability”) and embed them in a more formal structure. The framework was constructed iteratively over the course of several months while the exact variables for inclusion and precise terminology were decided.
While many of the classic terrain variables in the framework (e.g., slope steepness) could be extracted from DEMs or GPS tracks, McClung (2002) points out that perception is the link between information processing and behavior, and that choices result from a perceived interpretation of the environment. Despite the negative reputation that heuristic decision-making has gained (e.g., heuristic “traps:” McCammon, 2004), there is a growing body of literature that highlights the value and quality of heuristic choices in general (Gigerenzer and Gaissmaier, 2011; Todd and Gigerenzer, 2000), as well among ski guides (Haegeli and Atkins, 2016). Therefore, in an effort to understand guide decisions, the main focus of the framework is to capture information relative to their perceptions rather than to catalogue scientifically precise measurements of each run’s characteristics. For example, the framework compartmentalizes continuous variables into decision-relevant categories (e.g., slope steepness broken into four steepness levels). Some variables pertain to the presence or absence on specific features on a run (e.g., types of skiing terrain), and general subjective assessments describe the overall perceived nature of terrain as it pertains to run’s entirety (e.g., overall skiing experience). The measurement of perceived terrain characteristics with categorical and ordinal levels is the way the framework describes terrain as it relates to decision-making, and this method of describing terrain in ordinal and categorical ways effectively captures guide expertise that is both measurable and interpretable.

The relevant factors for characterizing ski runs that emerged from this work are grouped into five main themes of information relevant to operational decision-making: access, skiing experience, usability, hazard potential, and mitigation (Figure 3).

**Figure 3**  The foundation of the terrain characterization framework breaks skiing terrain down into five primary themes.

**Access** describes how easy or challenging it is to physically get to a run once the helicopter has arrived in the neighborhood of the run. “General accessibility” is
therefore a measurement of how easy it is to get to a run from close by, as opposed to its accessibility from the lodge independent of other runs. The factors included in this theme relate to physical barriers that restrict a guide’s ability to get to a run, such as the weather conditions required for safe access, the quality of visual references at the landing or pickup sites, and whether these sites have any additional outstanding flight hazards. Also included in the access characterization is whether there are any known flying incidents or near misses on the run, as this information might affect how they perceive the general accessibility of a run.

**Skiing experience** details the nature and quality of the skiing guests will encounter on a run. The factors contributing to this theme are centered around the terrain characteristics that pertain to skiing and variables that contribute to the experience as a whole, both positive and negative, and the variables in this theme combine to describe the overall benefits a run can provide guests (which is attractive for guiding). Specifically, it covers the presence of different types of skiing terrain (e.g., glaciated terrain, glades, dense forest, etc.), whether or not the skiing provides special experiences for guests (e.g., pillow drops and airtime, deep powder skiing, breathtaking scenery, etc.), whether there are any negative skiing challenges (e.g., dense vegetation, flat sections), and overall skiing difficulty.

While the Skiing experience theme focuses on the guest experience, **Usability** describes how a run can be used by guides to fulfill the operational goals of the team. Factors related to usability include the capacity of a run (i.e., number of fresh tracks it can support) and whether environmental conditions (e.g., freezing levels), the presence of wildlife that must be avoided, or other types of backcountry users who might interfere with the guest experience. Usability also includes the concept of ‘operational role,’ which describes a particular function that a run might offer to the guiding team. ‘Signature runs’, for example, might be coveted runs that define the essence of an operation and might be used in promotional material. ‘Destination runs’ are objectives that offer the highlight of a neighborhood, circuit, or even an entire day of skiing. Some other runs are more utilitarian; ‘jump runs’ serve to connect other high-quality runs and complete a circuit, and ‘time management runs’ effectively keep a group busy while performing necessary operational tasks, such as refueling. Others provide ideal scenic and environmental conditions to entertain guests while having lunch in the field (‘lunch runs’).
Finally, some runs serve guides in specific weather conditions, such as ‘Safe and accessible runs’ and ‘Critical bad weather runs.’

**Hazard potential** outlines the terrain features and typical snowpack characteristics that contribute to the severity of avalanche and non-avalanche related hazards. The types of terrain features in hazard potential theme include steepness of the most serious slopes, the size of these steep slopes, specific avalanche related terrain hazards (e.g., high consequence terrain, overhead avalanche hazard, etc.), whether the area is particularly known for snow conditions that promote avalanche hazard (e.g., prone to wind slabs, surface hoar farm, etc.), and the presence of any hazards unrelated to avalanches (e.g., cornices directly affecting ski line, tree well hazard, etc.). These variables are well known in the guiding community (Association of Canadian Mountain Guides, 1999) and have been shown to affect guide choices (Thumlert and Haegeli, 2018), but the framework describes these terms in ways more relevant to human decision-making. Rather than being a continues variable measured in degrees, slope steepness is broken down into a four-level Likert scale that is more representative of how guides perceive this variable when making their quick decisions.

The final theme **Mitigation** captures options the guiding team might have to control avalanche hazard. This includes the use of explosives to reduce avalanche hazard within the skiing terrain or overhead hazard threatening a ski run or landing sites from above. Another possibility is to mitigate avalanche hazard by maintenance with skier traffic, or it is possible that critical slopes commonly self-stabilize through natural avalanching. The mitigation theme also includes whether there have been any guiding incidents or near misses.

While these five themes aim to represent distinct aspects for characterizing ski runs, they are still closely related via certain elements that pertain to multiple themes. The specific types of skiing terrain, for example, are included under Skiing Experience but also relate to Hazard Potential and Mitigation.

Another important feature of this framework is that different terrain attributes relate to different terrain spatial scales, so the variables in the framework are stratified into four hierarchical levels: run clusters, ski runs, ski lines, and elevation bands. In mechanized skiing, ‘run clusters’ are groups of runs guides can use together without
moving “too much” once they are in that particular “neighborhood” (e.g., head of a valley). Clusters are distinct from each other through a combination of distance and/or the existence of substantial terrain barriers affecting access (e.g., ridge, pass, white space, big lake to cross). Run clusters are an important unit for guides especially when they are considering the efficiency of a day’s skiing circuits. ‘Ski runs’ are areas of skiing terrain that are discussed as a unit during the morning guides’ meeting. The terrain characteristics within a ski run are sufficiently similar for the guiding team to collectively decide whether the whole run is open or closed for guiding given the expected snow and weather conditions (Sterchi and Haegeli, 2019). It is important to note that the size of ski runs in mechanized skiing can range from tens of hectares to several square kilometers. Due to their size, many ski runs have multiple landings and pickups, and they can be skied in several distinct ways. These skiing variations are referred to as ‘ski lines.’ A run that is considered open during a morning guides’ meeting has at least one ski line that can be guided safely under the expected conditions. Since ski lines are a tangible unit of terrain that guides have to commit to when they decide to ski a run, ski lines are the focus of the terrain characterization framework and the present analysis. However, since the character of certain skiing experiences and hazards can change substantially at different elevations on a ski line, the framework further stratifies ski lines by the three elevation bands (alpine, treeline and below treeline) in terrain parameters where this is a meaningful distinction (Figure 4). Structuring the terrain characterization according to this hierarchy makes the framework more reliable and more efficient as the information is always collected at the most relevant spatial scale. For example, types of skiing terrain can change dramatically between different elevation bands, but operational roles can apply to an entire run.
2.2. Online Implementation of Terrain Survey

To collect terrain assessment data, I collaborated with the SARP research team to build a comprehensive website for guides to complete an online terrain survey structured entirely around the terrain characterization framework (https://avterrain.avalancheresearch.ca). The website had separate sections for the terrain questionnaire forms, guide background information, survey instructions, and terminology definitions. The main page displayed the list of runs to be assessed, with progress indicators showing how much of each run’s questionnaire had been completed.

Each run included in the terrain survey had its own page that included a terrain photo giving an overview of the run and had the ski line(s) to be assessed drawn on.
(Figure 5). Run photos are broadly used in the mechanized skiing industry when discussing the nature of runs during guides meetings. Below the terrain photo, the page was structured with two sets of nested tabs. The first row of tabs facilitated navigation between the different lines of the run, and the second row of tabs separated the questions for each line according to the five main themes of the terrain characterization framework: access, skiing experience, usability, hazard potential, and mitigation. The line tabs also included an extra tab for general questions that related to the entire run (e.g., personal familiarity with the run, conflicts with other backcountry users). Specific terrain characterization questions were structured according to the spatial terrain hierarchy described in Section 2.1 (i.e., cluster, run, line, and elevation band). Once participating guides completed the terrain questionnaire for each line of a run, the website generated a concise assessment summary for that run (Figure 6).
Figure 5

Screen shot showing run photo with two ski lines and the survey questionnaire; the top row of tabs toggle between questions regarding the entire run (“General”) and the two lines (“Blue line” and “Black line”); the bottom row of tabs toggle between the five terrain assessment categories of questions for each line (“Access”, “Skiing Experience”, “Usability”, “Hazard Potential”, and “Mitigation”).
Figure 6  Screen shot of comprehensive run summaries generated by the website after survey assessments were completed.
To allow participating guides to express their perceptions of a run in a comprehensive way, the survey used three types of questions: questions targeting factual information that is otherwise difficult to access, questions capturing personal or operational experiences associated with ski runs or lines, and questions allowing participants to express their overall affective response to ski runs or lines.

Questions targeting factual information included questions about the physical terrain characteristics of a ski run or line using binary, Yes/No checkboxes (e.g., type of terrain, snowpack hazards, special skiing experiences). Graduated factual characteristics (e.g., slope steepness, slope size, skiing difficulty) were assessed using ordinal response levels, which, while not as precise as scientific measurements, more effectively capture guides’ perceptions of terrain in meaningful, decision-relevant categories. Slope incline, for example, was divided into three basic categories including gentle (typically not steep enough to produce significant avalanches), moderately steep (sufficiently steep to produce significant avalanches under specific conditions), and steep (sufficiently steep to produce significant avalanches under typical conditions).

Other ski run or line characteristics that were captured with this type of question included conflicts that may exist with other backcountry user groups and the cumulative number of fresh tracks a run can accommodate. To allow guides to describe particular features that were not already available as response options, most survey questions also had an ‘other’ option with a free-form text field. This also allowed guides to enter their personal and operational experiences associated with a ski run or line, such as past avalanche incidents and/or near misses.

The final type of question included in the survey was aimed at capturing overall subjective assessments of how guides perceived the line as a whole. The guiding community has repeatedly highlighted the importance of “gut feeling” in guide decision-making (e.g., Adams, 2005; Atkins, 2014). In cognitive psychology, the primary component to this somatic decision-making approach has been labelled the “affect heuristic” (Finucane et al., 2000) or “risk as feeling” (Loewenstein et al., 2001) when used to evaluate hazardous situations. Slovic et al. (2004) describe affect as a “faint whisper of emotion”, a personal impression of goodness or badness experienced consciously or subconsciously as a feeling. Extensive research in cognitive psychology has highlighted that affect plays a central role in the fast and effortless intuitive decisions that are produced by the “experiential system” (Epstein, 1994) or “System 1”
(Kahneman, 2011). The use of the affect heuristic (and other heuristics) as mental tools is particularly prevalent in complex decision environments that tend to overwhelm the “analytical system” or “System 2”. Following the description of Slovic et al. (2004), affective responses in the context of guiding can be viewed as the emotional encoding of someone’s comprehensive terrain knowledge and years of practical experience that serve as orienting mechanisms, helping them quickly and efficiently navigate their complex, uncertain, and time-pressured decision environment. Therefore, to allow participants to express their intuitive gut feeling of a ski line, most assessment themes included an overarching, Likert-scale question. Examples of these types of questions include ‘overall friendliness’ with respect to hazards, and ‘overall guide-ability’ of a run. The ordinal response classes to capture the relative goodness or badness were deliberately kept vague (e.g., overall friendliness: very unfriendly, unfriendly, neutral, friendly, very friendly) to prevent participants from approaching the question too analytically; highly specified definitions of these terms would draw guides away from what these terms meant to them.

To ensure the survey captured terrain perceptions in the most meaningful and decision-relevant way, the survey utilized terrain terminology (e.g., ‘jump run’) and concepts (e.g., ‘friendliness’) already used in the mechanized skiing community. A full description of all questions included in the survey, their potential responses, and the terrain level(s) it was associated with can be found in Appendix A.

To provide important context for the analysis of terrain perceptions, I also collected data on guide characteristics. Personal background questions included gender (male, female, or other text field), age (number of years), number of winters guiding in mechanized skiing and at their current operation, highest professional guiding credential (IFMGA Full Mountain Guide, ACMG Full Ski Guide, Canadian Ski Guide Level 1-3, or other text field), what type of workplace mentorship they had access to after certification, and what professional role they occupy at their current operation (owner, operator, operations manager, lead guide, guide, other text field). To assess how the general nature of snow and avalanche conditions might affect terrain perceptions, the survey also asked participants to specify in what snow climate they initially learned their guiding skills (maritime, transitional, or continental) and in what snow climate they have spent most of their career.
The terrain characterization framework, the online implementation of the terrain survey, and run summaries from initial survey completions have been presented at the Canadian Avalanche Association Spring Meeting (2018), the 2018 International Snow Science Workshop in Innsbruck, Austria (Wakefield et al., 2018), and various guides trainings meetings (incl. Canadian Mountain Holidays, Northern Escape Heliskiing, Selkirk Tangiers Heli Skiing, Selkirk Wilderness Skiing, Whistler Heliskiing).

2.3. Data Collection

For the present study, I collaborated with guides from two commercial heli-skiing operations in British Columbia, Canada. Northern Escape Helicopters (NEH) is located in Terrace, B.C., in the Skeena Mountains. They have been operating within a 6000 km² tenure region over the past 14 years, with multiple helicopters and snowcats as backup for poor weather days. NEH uses a Bell 407 (four guests), a Eurocopter AS350 (“A-Star;” four guests), and an AgustaWestland Koala (six guests), which allows them to advertise smaller group sizes and a more intimate experience (https://www.neheliskiing.com). The elevation of their skiing terrain exists between 500 – 2000 m above sea level. Their tenure region has 260 established runs available for skiing, however this research focused on their home drainage, an area with 80 runs called Promised Land. NEH has approximately 10 guides on staff within their team. Selkirk Tangiers Heli Skiing (STHS) is located in Revelstoke, B.C., on the boundary of the Selkirk and Monashee Mountain ranges. They have been operating within a 2000 km² tenure region for 40 years, with multiple helicopters. STHS also flies the 407 and the AS350 helicopters for small and private groups, however their largest helicopter is the Bell 205, which is used for shuttling multiple groups of up to 11 guests each (https://www.selkirk-tangiers.com). Their terrain ranges from 750 – 2750 m above sea level with almost 500 established ski runs. The guiding team at STHS is substantially bigger than at NEH, employing approximately 25 full- and part-time guides each winter.

Selection of the runs to be included in the present study was an important consideration. I worked with lead guides at both operations to select runs frequented enough such that all participating guides could assess them and runs that include all types of terrain present in each operation. A geographical overview of the runs included in this analysis at the two operations is shown in Figure 7.
Figure 7  Geographical overview of (a) NEH and (b) STHS tenure regions. White dots are all ski runs in the operation and yellow dots are ski runs included in this study.
2.4. Line Use Data

While the online survey was designed to capture how guides perceive terrain, the data it generated could not provide any insight into how guides weigh different run characteristics against each other when actively deciding where to ski. To address this question, I needed to statistically regress ski line usage against the collected terrain characteristics and the guide terrain perceptions. I took advantage of the ongoing GPS tracking research being conducted in partnership between NEH and SARP. NEH lead guides have been equipped with passive GPS tracking units that record their location every four seconds since Dec. 2014. In the five winter seasons since the start of this initiative, SFU’s research team has tracked slightly more than 5000 NEH ski descents on close to 800 guiding days (P. Haegeli, personal communication, May 1, 2019). Since the research team has also digitized the NEH ski lines included in this survey as polygons,
ski line use frequencies could easily be derived by intersecting the GPS tracks with the ski line polygons. To ensure meaningful counts, only intersects of at least 200 m in length were used for calculating the ski line use frequencies. The distance from each ski line to the lodge was calculated using the coordinates of the centroid of the ski line polygon and the NEH lodge. The created the Line use variable in the data set.

2.5. Statistical Analysis

I employed several regression models to examine how terrain characteristics influence guide perception and line use (Figure 2). Four ordinal logistic regression models revealed which specific terrain factors predicted guide perceptions of ski lines (one each for Overall friendliness, Overall skiing experience, General accessibility, and Overall guideability), and a single Poisson regression model took the guides’ general perceptions of a line, a line’s Operational role, and Distance from lodge as independent variables to predict how often a line is skied (Line use), measured by the number of GPS tracks.

Before any statistical modeling could take place, the perception data from the survey data required preprocessing due to the hierarchical structure of the terrain representation in the survey (i.e., run cluster, ski run, ski line, and elevation band described in Section 2.1). Since ski lines were the scale at which individual assessments were analyzed, the assessments made at the run and elevation-band level needed to be expanded or aggregated to the line level. Elevation-band specific assessments were aggregated by taking the assessment that most limits guides’ ability to ski that line. For example, since steepness was assessed for each elevation band within a line, the steepness of a line for analysis was recorded as the maximum steepness of the three elevation bands. A converse example is friendliness, which was recorded as the minimum assessment over the three elevation bands. Survey questions that assessed the run as a whole (such as familiarity) were replicated to be the same for all associated lines.

To get a sense of the dataset and prepare for the modeling process, I first explored the large collection of variables available to be included in the statistical analysis. I first explored the mean level and range in assessments for the perception variables using plots showing the general response distributions as well as customized
sunflower plots. To ensure statistical robustness, I examined the number of responses in the levels of each variable to make sure they could be included in the analysis. I primarily performed these comparisons using tables of response levels and spine plots. This was especially important for binary predictor variables as the distributions of the response levels should not be too unbalanced to ensure reliable model parameter estimates. Binary variables with too few “Yes” responses were therefore omitted from the analysis (n < 15). Similarly, I examined the relationships between potentially colinear predictor variables to ensure their influence on the subsequent response variable was meaningful and representative of reality. These relationships emerged during initial plotting and the modeling process, and statistical evidence of associations was quantified using Pearson’s correlation for numeric variables and Kendall rank correlation (Kendall’s τ) for ordinal variables.

The variable Overall hazard potential was calculated by reverse coding the survey assessments for Overall friendliness. Part of the survey’s ability to gather meaningful data from guides is because it employs guiding terminology, and “friendliness” is an established term guides use to describe how they feel about the hazard potential of a line (P. Haegeli, personal communication, May 1, 2019). However, to more meaningfully contrast the hazard potential of a run to its skiing experience and operational value, I reversed the levels of “overall friendliness” to create the variable Overall hazard potential (ordered by increasing severity: “Very Friendly,” “Friendly,” “Neutral,” “Unfriendly,” and “Very Unfriendly”).

Because each guide made multiple assessments and each run contained multiple lines (repeated measures), traditional regression with a strict independence assumption was inappropriate for the present analysis (Kutner et al., 2005; Long, 2012). To address this issue, I used a mixed effects modeling approach that incorporated these interdependencies by expanding the regression models described above with “random effects” (Harrison et al., 2018). In my analysis, I included random intercepts to better capture the variability in the data beyond the global error term. The OLR perception models contained random intercepts for Guide and Run, and the Poisson line use model had random intercepts for Run. The resulting random effects offered valuable insight into how observations recorded from individual guides or within individual runs tend to deviate from the average values of the whole data set. Because the Operation variable only had two levels, I included it as an explicit binary fixed effect (with levels NEH and
STHS) and tested for interaction effects between Operation and the other terrain variables.

The four OLR perception models take terrain characteristics as predictor variables and a general perception as the response variable. In an OLR model, the logistic (sigmoid) function is used to link the probability of the dependent variable being in a specific ordinal category or lower to a total of \( p \) predictor variables:

\[
\log \left[ \frac{P(Y_i \leq j)}{1 - P(Y_i \leq j)} \right] = \alpha_j + \sum_{k=1}^{p} \beta_k X_{ik} - u_1(Run_i) - u_2(Guide_i) \tag{1}
\]

for \( j = 1, 2, \ldots, J - 1 \)

The variables in this equation can be interpreted as follows:

- The left side of the equation represents the log-odds (logarithm base e of the odds) of observing a level \( j \) in the response variable \( Y_i \) or lower. This is the log of the ratio of the probability \( Y_i \) will be at level \( j \) or lower (i.e., \( P(Y_i \leq j) \)) divided by the probability \( Y_i \) will be higher than level \( j \) (i.e., \( 1 - P(Y_i \leq j) \), which is the same as \( P(Y_i > j) \)). \( Y_i \) has \( J \) total ordered levels.

- The subscript \( i \) identifies each observation, which is a row of data relating the recorded assessments of each predictor variable \( X_{ik} \) to the corresponding value of \( Y_i \).

- After the transformation to the left side of the equation, the \( \beta_k \) coefficients operate like ordinary regression parameters. Each parameter \( \beta_k \) represents the multiplicative effect of each predictor variable \( X_{ik} \), so a parameter estimate of 1.0 means the logit of \( Y_i \) being larger than level \( j \) (\( P(Y_i > j) = 1 - P(Y_i \leq j) \)) increases by 1.0 for each unit increase in \( X_{ik} \). In this thesis I refer to this as the effect of a predictor variable \( X_{ik} \). As in ordinary logistic regression, these can be converted into odds-ratios (OR) for easier interpretation by exponentiating the parameter estimates: \( e^{\beta_k} \). Similar to the interpretation of the parameter estimates, an OR for \( X_{ik} \) is the ratio of the odds \( Y_i > j \) for any value of \( X_{ik} \) to the odds \( Y_i > j \) for \( X_{ik} + 1 \) (a one unit increase in \( X_{ik} \)). Because of the negative sign in front of the
predictors and the random effects, a positive increase in a regression coefficient \( \beta_k \) relates to an increase in the cumulative probability \( Y_i \) is greater than level \( j \), \( P(Y_i > j) \).

- The \( \alpha_j \) term represents the intercepts for each level \( j \). Note that due to the fact that the response variable in OLR has ordered categorical levels, there is only one set of regression coefficients \( \beta_k \) for all \( j \) levels of the response variable \( Y_i \), and the only difference in the equations for each level \( j \) is the intercept term, \( \alpha_j \). These intercepts are threshold parameters that determine the horizontal shift of the logistic function and represent the transition (or “cut-off” point) from a level \( j \) to the next level \( j+1 \). For example, the difference between levels \( j = 2 \) and \( j = 3 \) in \( Y_i \) is represented by a shift in the logistic curve from \( P(Y_i \leq 2) \) to the logistic curve for \( P(Y_i \leq 3) \) in the direction of a predictor, say \( X_{11} \), by \( \frac{\alpha_2 - \alpha_3}{\beta_1} \) units. These proportional shifts apply to all the predictors (as all levels of \( Y_i \) have the same regression coefficients \( \beta_k \)), which is why McCullagh, (1980) calls it a “proportional odds” model.

- The two terms at the end \( u_1(\text{Run}_i) \) and \( u_2(\text{Guide}_i) \) represent the random effects of \( \text{Run} \) and \( \text{Guide} \), which account for variability (heterogeneity) in the data due to guide-to-guide and run-to-run differences. Each \( u \) term is a set of individual random intercepts (for each guide and each run), assumed to be normally distributed with mean 0 and variances \( (\sigma_{u_1})^2 \) and \( (\sigma_{u_2})^2 \). The model estimates these two variances in addition to the regression coefficients, and a random intercept can be estimated for each run and each guide. I report the standard deviation (SD) of these variances, \( \sqrt{\sigma_u^2} \), in the results.

The final behavioral model used the four guide perceptions in conjunction with ski line characteristics as predictor variables and counts of GPS tracks as the response variable. I used Poisson regression for this model because the response variable consisted of count data, which can only take on values of positive integers, and the probability of extremely high counts is assumed to be low. Therefore, the error term in
Poisson regression is assumed to have a Poisson distribution. A total of \( p \) predictor variables are related to the mean count of the response variable \( \mu_i \) by the equation:

\[
\log(\mu_i) = \alpha + \sum_{k=1}^{p} \beta_k x_{ik} + u(\text{Run}_i) \tag{2}
\]

While \( \mu_i \) on the left side of Equation (2) represents the average number of the expected uses of observation \( i \), the right side of Equation (2) is exactly the same as in Equation (1) except that there is only a single intercept, \( \alpha \). Because of the logarithmic link function, the effect size of individual predictor variables \( x_{ik} \) are also expressed by applying the exponential function, \( e^{\beta_k} \), to the associated parameter estimates \( \beta_k \) like in the ordinal logistic regression model. However, instead of representing the ratio of the odds, each exponentiated parameter of a Poisson regression describes the multiplicative factor by which the counts increase \((\beta_k > 1)\) or decrease \((\beta_k < 1)\) with one-unit increase in the predictor. The interpretation for binary and nominal predictor variables follows the same pattern as described for the OLR model, as does the interpretation of the random effect (only a single random effect for \( \text{Run} \) in this model).

To construct each model, I followed an iterative process to select predictor variables from the pool of relevant parameters based on what would logically have an impact on guide perception. Much of this was informed by the exploratory data analysis. In the model-construction process, I retained only predictor variables that showed statistical evidence of having an effect on the response variables after each round of adding variables, and I used \( p < 0.05 \) as the cut-off point for this criterion. Where appropriate, ordinal predictors were converted into numeric predictors to produce parsimonious models with only the necessary number of parameters. I used the Akaike Information Criterion (AIC; Akaike, 1974), the Bayesian Information Criterion (BIC; Schwarz, 1978), and performed analyses of variance (ANOVAs) to help decide between similar versions of each model.

Some ordinal predictor variables showed parameter estimates similar in magnitude for each level during the modeling process. If these estimates were nearly identical, I assumed this was evidence of a linear effect of the predictor, and I converted these ordinal factors to be continuous numeric variables with integer levels (e.g., Best referenced landing).
I performed all analyses using R (R Core Team, 2019). To explore various model configurations and construct my final models, I used the “clmm” function in the ordinal package (Christensen, 2019) for the four OLR models and the “glmer” function in the lm4 package (Bates et al., 2015) for the Poisson regression model. The effects R package (Fox and Weisberg, 2018) was used to generate visualizations of the cumulative probabilities of observing each response variable level in the ordinal regression models.
Chapter 3.

Results

3.1. Descriptive Analysis

The final dataset for the present analysis consisted of 721 ski line assessments made by 13 guides in total. These assessments were performed on 137 ski lines associated with 84 runs within the NEH and STHS tenure areas. There were 521 assessments (72% of all assessments) made by seven guides at NEH (83 lines in 39 runs), and 205 assessments (28% of all assessments) were completed by six guides at STHS (54 lines in 45 runs).

The participating guides at NEH ranged in age from 33 to 68 years old with 5 to 20 years of experience in mechanized guiding and 1 to 14 years of experience guiding specifically at NEH. The operational roles of participating NEH guides included “Guide” (n = 3), “Lead Guide” (n = 2), and “Operations Manager” (n = 2), and NEH guides were certified as “IFMGA/ACMG Full Mountain Guide” (n = 3), “ACMG Full Ski Guide” (n = 2), or “ACMG Assistant Ski Guide” (n = 1). All NEH guides reported they learned to guide in the same snow climates in which they had the most guiding experience: two were from a maritime snow climate (e.g., Coast Mountains), two from a transitional snow climate (e.g., Columbia Mountains), and three were from a continental snow climate (e.g., Rocky Mountains). All seven NEH guides identified as male.

At STHS, guides ranged in age from 41 to 62 years old with 8 to 30 years of experience both in mechanized guiding and guiding at STHS. All participating STHS guides reported they were a “Lead Guide” (n = 6), and STHS guides were certified as either “IFMGA/ACMG Full Mountain Guide” (n = 4) or “ACMG Full Ski Guide” (n = 2). All guides at STHS reported that they learned to guide and had the most guiding experience in a transitional snow climate. One STHS guide identified as female, whereas the other five guides identified as male.
The distributions of assessments for the levels of the four perception variables are shown in Figure 8.

Figure 8  Distribution of assessments for each level of a) General accessibility (levels from lowest to highest are “need perfect conditions,” “conditions need to lineup,” “often possible,” and “almost always”), b) Overall skiing experience, c) Overall hazard potential, and d) Overall guideability.
I expected *Familiarity* to be an influential variable in most of the models, and this distribution was skewed as guides generally reported high levels of *Familiarity* for most assessments (Figure 9).

![Distribution of Familiarity ratings.](image)

**Figure 9**  Distribution of *Familiarity* ratings.

To examine the relationships between *Familiarity* and the four perception variables, I performed correlation tests to examine any potential collinearity between the mean values of each over all lines at both operations (Figure 10). It is important to note that while subjective, *Familiarity* is not a perception variable in the same way that *General accessibility*, *Overall skiing experience*, *Overall hazard potential*, and *Overall guideability* are. Some of the strongest correlations are the negative relationship between mean *Overall hazard potential* and *General accessibility*, and the negative relationship between mean *Overall hazard potential* and *Overall guideability*. The positive relationship between mean *Overall accessibility* and *Familiarity* is unsurprising because guides ski terrain they can easy access more often.
Correlations of General Perception Variables

![Correlations of General Perception Variables](image)

Figure 10  Correlations between mean values of the general perception variables (General accessibility, Overall skiing experience, Overall hazard potential, and Overall guideability) and Familiarity.

Response level counts and proportions for the binary predictor variables are shown in Table 1. These are only the binary variables that emerged as significant predictors in the perception models. While the counts are relatively even for most predictors, some are heavily skewed due to the rare occurrences of some particular features (e.g., Extreme alpine faces, Cutblocks, and Open season line).
Table 1  Response distributions of select binary predictor variables included in the five models.

<table>
<thead>
<tr>
<th>Survey Theme</th>
<th>Variable</th>
<th>Response</th>
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<th>Yes</th>
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<tr>
<td></td>
<td></td>
<td>Count</td>
<td>%</td>
<td>Count</td>
</tr>
<tr>
<td>Access</td>
<td>Pickup flight hazard – Lrg cycle overhead hazard</td>
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<td></td>
<td>Ski terrain – glaciated terrain</td>
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<td></td>
<td>Ski terrain – extreme alpine faces</td>
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<tr>
<td></td>
<td>Ski terrain – near ridge top steep slopes</td>
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<td></td>
<td>Ski terrain – cut blocks</td>
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<td>Ski terrain – moraine slopes</td>
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<td>Special ski experience – breathtaking views</td>
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<td></td>
<td>Special ski experience – big vertical</td>
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<td></td>
<td>Ski challenges – flat Sections</td>
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<td>Snow hazard – wind slabs</td>
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<td>Snow hazard – surface hoar farm</td>
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<td>Terrain hazard – high consequence terrain</td>
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<td>Hazard Potential</td>
<td>Operational role – safe and accessible</td>
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<td>Operational role – signature line</td>
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<td>Operational role – destination line</td>
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3.2. Perception Models

3.2.1. General Accessibility

The average ratings and ranges in assessments for General accessibility at the two operations give a summary of how guides perceive the accessibility of the ski lines included in the study. When sorted by average assessment, the sunflower plots in Figure 11 show how the individual ski lines ranked by mean General accessibility and on which lines there was the most agreement among guides at the two operations.
Figure 11  Sunflower plots visualizing assessments of General Accessibility for each line at a) NEH and b) STHS. Each “petal (orange tick marks)” surrounding a point represents an assessment at that level. The red tick marks represent the mean assessment for that specific line, and the vertical yellow bars represent the range in assessments for that line.
Assessments of General Accessibility at STS

Figure 11 Contd.
Initial explorations of the terrain characteristics pertaining to perceived accessibility showed likely effects of *Landing elevation* and the visual quality of the *Best referenced landing* (Figure 12). Higher levels of both of these variables were visually associated with higher levels in *General accessibility*.

![Figure 12](image-url)  
**Figure 12**  
Proportional relationships between *General accessibility* and *Best referenced landing* and *Landing elevation*.

Exploratory modeling indicated a positive effect of experience with a *Helicopter incident* on perceived *General accessibility*, which seems counterintuitive. There was a relatively large proportion of *Helicopter incidents* associated with higher levels of *General accessibility* (Figure 13a), but further examination of the distribution of *Helicopter incidents* revealed that they all occurred when guide *Familiarity* was also high (Figure 13b), and there appeared to be a strong relationship between *Familiarity* and *General accessibility* (Figure 13c). While there was no statistical evidence of an ordinal association between *Helicopter incident* and *General accessibility* (Kendall rank correlation: $\tau = 0.07, p = 0.055$), there was evidence of an ordinal association between *Helicopter incident* and *Familiarity* (Kendall rank correlation: $\tau = 0.12, p = 0.001$).

Therefore, I concluded *Helicopter incident* was most likely signaling for *Familiarity*, and because *Familiarity* is a result of better access (and more frequent use) and not a cause, it was appropriate to exclude it from the general accessibility model.
Figure 13  Spine plots visualizing the relationships between awareness of or personal experience with a Helicopter incident, General accessibility, and guide Familiarity with a line: a) large proportion of Helicopter incident experiences in high levels of General accessibility, b) positive relationship between Familiarity and Helicopter incident, and c) positive relationship between Familiarity and General accessibility.

My OLR analysis revealed statistical evidence that four variables in the terrain framework affected General accessibility (Table 2). The largest positive effect emerged for Landing elevation at the treeline level, with landing(s) at treeline having a strong positive effect of 0.700 (SE 0.353, p < 0.001), which was quite pronounced compared to below treeline (Figure 14d). The other feature with a positive effect on General accessibility was the quality of the Best referenced landing (Figure 14a), which had a
parameter estimate of 0.409 (SE 0.204, p = 0.045). The presence of pickups exposed to overhead (OH) avalanche hazard (Large cycle OH hazard) during large cycles had a negative effect of -0.472 (SE 0.196, p = 0.016) on General accessibility. The individual influence of each effect on the probability of observing each level of General accessibility are visualized in Figure 14.

**Table 2  General accessibility model summary.**

<table>
<thead>
<tr>
<th>Attributes and levels</th>
<th>Estimate</th>
<th>SE</th>
<th>p-value</th>
<th>OR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>a) Intercepts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perfect – Lineup</td>
<td>-3.298</td>
<td>0.566</td>
<td>&lt;0.001</td>
<td>-</td>
</tr>
<tr>
<td>Lineup – Often</td>
<td>-0.591</td>
<td>0.525</td>
<td>0.260</td>
<td>-</td>
</tr>
<tr>
<td>Often – Always</td>
<td>2.059</td>
<td>0.530</td>
<td>&lt;0.001</td>
<td>-</td>
</tr>
<tr>
<td><strong>b) Fixed effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best referenced landing*</td>
<td>0.409</td>
<td>0.204</td>
<td>0.045</td>
<td>1.506</td>
</tr>
<tr>
<td>Pickup flight hazard – Lrg cycle overhead hazard</td>
<td>-0.472</td>
<td>0.196</td>
<td>0.016</td>
<td>0.624</td>
</tr>
<tr>
<td>Landing elevation</td>
<td>0.000</td>
<td>-</td>
<td>-</td>
<td>1.000</td>
</tr>
<tr>
<td>Alpine (base level)</td>
<td>1.516</td>
<td>0.353</td>
<td>&lt;0.001</td>
<td>4.554</td>
</tr>
<tr>
<td>Treeline</td>
<td>0.700</td>
<td>0.484</td>
<td>0.148</td>
<td>ns</td>
</tr>
<tr>
<td>Below treeline</td>
<td>-1.746</td>
<td>0.968</td>
<td>0.071</td>
<td>ns</td>
</tr>
<tr>
<td><strong>c) Interaction effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation – STHS : Best referenced landing*</td>
<td>0.908</td>
<td>0.376</td>
<td>0.016</td>
<td>2.479</td>
</tr>
<tr>
<td>Operation – STHS : Landing flight hazard – Low gross weight landing</td>
<td>-1.492</td>
<td>0.530</td>
<td>0.005</td>
<td>0.225</td>
</tr>
<tr>
<td><strong>d) Random intercepts (standard deviations)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ski run</td>
<td>1.023</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Guide</td>
<td>1.041</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Numeric variable. Associated OR is per unit increase.
ns Not significant OR omitted.
Figure 14  Effects plots of select predictor variables on General accessibility showing a) positive effect of visual quality of the Best referenced landing, b) negative effect of Low gross weight landings at STHS only (interaction effect), c) negative effect of pickups exposed to Large cycle OH hazard, and d) positive effect of Treeline landings.

The positive interaction effect between Operation and Best referenced landing indicated that guides at STHS perceive General accessibility to be higher on lines with the same quality of visual cues at the Best referenced landings than NEH.

Because there was only one instance of a line assessment that included Low gross weight landing from at guide at NEH, it was not possible to estimate reliable fixed and interaction effects for this predictor. However, to account for the effect of Low gross
weight landing on General accessibility ratings for STHS guides in the model, I added it as an explicitly coded main effect (i.e., observations of lines possessing a Low gross weight landing that were also at STHS). Since this fixed effect is conceptually an interaction effect, I listed it in Table 2 under interaction effects. However, there is no main effect for Low gross weight landing. The negative parameter estimate of the explicitly coded interaction effect indicates that Low gross weight landings has a negative effect on perceived General accessibility among STHS guides.

These results highlight that pickups and landings were a fundamental travel boundary that must be both appropriately safe and physically accessible by the helicopter before a guide can evaluate the skiing terrain contained in that line. Furthermore, the two interaction effects indicate that General accessibility at STHS is affected more strongly than NEH by the quality a landing’s visual references and weight capacity.

The random intercepts of two random effect variables are shown in Figure 15. Guide 5 and Guide 9 tended to rate General accessibility higher than average and Guide 10 and Guide 6 tended to give lower ratings. The SD of the random intercepts for Guide (SD = 1.041) was similar to the other perception models. The SD of the random intercepts for Run (SD = 1.023) was similar to the other models except for in the hazard potential model, where it was much smaller (SD = 0.399).
3.2.2. Overall Skiing Experience

The overall skiing experience model had the most potential predictor variables of all the models. Distributions of the binary types of skiing terrain, special skiing experiences, and skiing challenges are in Table 1. Mean assessment levels and ranges for Overall skiing experience are displayed in the sunflower plots in (Figure 16).
Figure 16  Sunflower plots visualizing assessments of *Overall skiing experience* for each line at a) NEH and b) STHS. This plot can be interpreted identically to Figure 11.
Assessments of Overall Skiing Experience at STHS

Figure 16  Continued.
There were many clear relationships in the data between predictor variables and distributions of *Overall skiing experience*, but it was surprising to see better skiing associated with higher levels of *Skiing difficulty* (Figure 17a). The number of observations of *Extreme alpine faces* (“Yes” responses) was quite low (n = 16), however it was still included in the analysis (and emerged as a predictor variable in the final model).

**Figure 17**  Spine plots of select predictor variables and associated proportions of *Overall skiing experience.*
Many types of skiing terrain, specific attributes of the skiing experience itself, skiing challenges, and the level of skiing difficulty emerged as significant predictor variables in my OLR analysis of guides’ general perception of the *Overall skiing experience* (Table 3). With the exception of only two skiing challenges, all predictor variables in the model had a positive effect on the perceived *Overall skiing experience*. The significant types of skiing terrain included in this model were *Glaciated terrain*, *Extreme alpine faces*, *Near ridge top steep slopes*, *Moraine slopes*, and *Planar slopes*. Of the special ski experiences listed in the survey, *Breathtaking views*, *Big vertical*, *Fall-line skiing* and *Deep powder* emerged as significant. While *Skiing difficulty* was positively associated with higher levels of *Overall skiing experience* (Figure 18b), only standout skiing challenges (*Flat sections* and *Dense vegetation*) reduced the perceived skiing experience (Figure 18e). *Familiarity* with the terrain had a positive effect on the perceived *Overall skiing experience* with a parameter estimate of 0.385 (SE 0.155, p = 0.013).
Table 3  Overall skiing experience model summary

<table>
<thead>
<tr>
<th>Attributes and levels</th>
<th>Estimate</th>
<th>SE</th>
<th>p-value</th>
<th>OR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>a) Intercepts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor – Fair</td>
<td>-2.456</td>
<td>0.778</td>
<td>0.002</td>
<td>-</td>
</tr>
<tr>
<td>Fair – Good</td>
<td>0.660</td>
<td>0.715</td>
<td>0.356</td>
<td>-</td>
</tr>
<tr>
<td>Good – Very good</td>
<td>4.024</td>
<td>0.730</td>
<td>&lt;0.001</td>
<td>-</td>
</tr>
<tr>
<td>Very good – Exceptional</td>
<td>7.927</td>
<td>0.787</td>
<td>&lt;0.001</td>
<td>-</td>
</tr>
<tr>
<td><strong>b) Fixed effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ski terrain – glaciated terrain</td>
<td>1.075</td>
<td>0.294</td>
<td>&lt;0.001</td>
<td>2.931</td>
</tr>
<tr>
<td>Ski terrain – extreme alpine faces</td>
<td>1.796</td>
<td>0.671</td>
<td>0.007</td>
<td>6.026</td>
</tr>
<tr>
<td>Ski terrain – near ridgetop steep slopes</td>
<td>0.461</td>
<td>0.200</td>
<td>0.021</td>
<td>1.585</td>
</tr>
<tr>
<td>Ski terrain – moraine slopes</td>
<td>0.549</td>
<td>0.237</td>
<td>0.020</td>
<td>1.731</td>
</tr>
<tr>
<td>Ski terrain – planar slopes</td>
<td>0.777</td>
<td>0.245</td>
<td>0.002</td>
<td>2.175</td>
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<tr>
<td>Special ski experience – breathtaking views</td>
<td>0.663</td>
<td>0.236</td>
<td>0.005</td>
<td>1.940</td>
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<tr>
<td>Special ski experience – big vertical</td>
<td>1.293</td>
<td>0.254</td>
<td>&lt;0.001</td>
<td>3.645</td>
</tr>
<tr>
<td>Special ski experience – fall line skiing</td>
<td>1.114</td>
<td>0.234</td>
<td>&lt;0.001</td>
<td>3.046</td>
</tr>
<tr>
<td>Special ski experience – deep powder</td>
<td>1.082</td>
<td>0.223</td>
<td>&lt;0.001</td>
<td>2.950</td>
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<tr>
<td>Ski difficulty Easy (base level)</td>
<td>0</td>
<td></td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.693</td>
<td>0.224</td>
<td>0.002</td>
<td>2.000</td>
</tr>
<tr>
<td>Challenging</td>
<td>1.225</td>
<td>0.326</td>
<td>&lt;0.001</td>
<td>3.404</td>
</tr>
<tr>
<td>Ski challenge – flat sections/traverses</td>
<td>-0.959</td>
<td>0.324</td>
<td>0.003</td>
<td>0.383</td>
</tr>
<tr>
<td>Ski challenge – dense vegetation</td>
<td>-1.100</td>
<td>0.347</td>
<td>0.002</td>
<td>0.333</td>
</tr>
<tr>
<td>Familiarity*</td>
<td>0.385</td>
<td>0.155</td>
<td>0.013</td>
<td>1.470</td>
</tr>
<tr>
<td>Operation – STHS</td>
<td>0.635</td>
<td>0.679</td>
<td>0.349</td>
<td>ns</td>
</tr>
<tr>
<td><strong>c) Interaction effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ski terrain – planar slopes : Operation – STHS</td>
<td>-0.943</td>
<td>0.437</td>
<td>0.031</td>
<td>0.389</td>
</tr>
<tr>
<td><strong>d) Random intercepts (standard deviations)</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ski run</td>
<td>0.983</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Guide</td>
<td>1.003</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Numeric variable. Associated OR is per unit increase.
ns Not significant OR omitted.
Figure 18  Effects plots of select predictor variables on Overall skiing experience showing a) positive effect of Familiarity, b) positive effect of Skiing difficulty, c) positive effect of Extreme alpine faces, d) positive effect of Big vertical, e) negative effect of Dense vegetation, and f) interaction effect of Operation and Planar slopes (larger effect at NEH).
While the OLR analysis did not reveal a fixed effect for *Operation*, an interaction effect between *Operation* and *Planar slopes* emerged, showing that participating STHS guides viewed *Planar slopes* less favorably as a part of the skiing experience than NEH guides (Figure 18f). The estimate of this interaction effect was -0.943 (SE 0.437, p = 0.031).

The random intercepts of two random effect variables are shown in Figure 19. Guide 1 and Guide 12 tended to rate *Overall skiing experience* higher than average and Guide 13 in particular tended to give lower ratings. The SD of the random intercepts for *Guide* (SD = 1.003) was similar to the other perception models. The SD of the random intercepts for *Run* (SD = 0.983) was similar to the other models except for in the overall hazard potential model, where it was much smaller (SD = 0.399).
3.2.3. Overall Hazard Potential

Counts of the levels of the binary snow hazard and terrain hazard variables included in the Hazard Potential model are in Table 1. The sunflower plots in Figure 20 show the mean and range in assessments for each line at the two operations.
Figure 20  
Sunflower plots visualizing assessments of *Overall hazard potential* for each line at a) NEH and b) STHS. This plot can be interpreted identically to Figure 11.
Assessments of Overall Hazard Potential at STHS

Overall Hazard Potential

Run/Line

Figure 20 Continued.
The obvious starting point when examining *Overall hazard potential* was to look for relationships in the most well-known hazard variables, such as steepness, exposure and terrain consequences. The spine plots clearly show the potential effects of these predictor variables (Figure 21).

![Spine plots showing potential relationships between Overall hazard potential and a) Steepness, b) Size of steep slopes (exposure), c) High consequence terrain, and d) Familiarity.](image)

**Figure 21** Spine plots showing potential relationships between *Overall hazard potential* and a) *Steepness*, b) *Size of steep slopes* (exposure), c) *High consequence terrain*, and d) *Familiarity*.

Similar to the counterintuitive effect of *Helicopter incident* on the general accessibility model, it appeared as though experiences with a *Guiding incident* occurred when *Familiarity* ratings were higher during initial examinations in the hazard potential
model (Figure 22). Further examination revealed strong statistical evidence of an ordinal association between these two variables (Kendall rank correlation: $\tau = 0.28$, $p < 0.001$).

![Spine plot visualizing the relationship between past experience with a Guiding incident (levels are no, awareness, and personal experience) and Familiarity.](image)

The final OLR model for perceived Overall hazard potential revealed that this response variable was heavily impacted by well-known hazard characteristics (Table 4). Slope steepness, Surface hoar farms (i.e., slopes that regularly grow surface hoar), slopes Prone to wind slabs, lines with High consequence terrain, and the Size of steep slopes all positively affected the perceived hazard potential of a line. Increases in Steepness result in the strongest increase in probability of observing a rating of “Very Unfriendly” (Figure 23). Cutblocks was the only specific type of skiing terrain to emerge with a negative estimate of -1.634 (SE 0.541, $p = 0.003$) (i.e., associated with friendlier terrain), which was the largest effect size in the model overall. It is worth noting that the effect of Cutblocks was negligible for all levels of Overall hazard potential except when increasing the probability of observing a “Very Friendly” assessment (Figure 23). This may be due to its unbalanced response levels (Table 1). Familiarity had a negative effect on Overall hazard potential (Figure 23), with an estimate of -0.573 (SE 0.126, $p < 0.001$). This means that more familiar ski lines were typically assessed friendlier or less hazardous. No interaction effects emerged in the hazard potential model.
Table 4  Overall hazard potential model summary

<table>
<thead>
<tr>
<th>Attributes and levels</th>
<th>Estimate</th>
<th>SE</th>
<th>p-value</th>
<th>OR</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Intercepts</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very Unfriendly – Unfriendly</td>
<td>-1.613</td>
<td>0.641</td>
<td>0.012</td>
<td>-</td>
</tr>
<tr>
<td>Unfriendly – Neutral</td>
<td>1.868</td>
<td>0.645</td>
<td>0.004</td>
<td>-</td>
</tr>
<tr>
<td>Neutral – Friendly</td>
<td>4.400</td>
<td>0.663</td>
<td>&lt;0.001</td>
<td>-</td>
</tr>
<tr>
<td>Friendly – Very Friendly</td>
<td>8.126</td>
<td>0.748</td>
<td>&lt;0.001</td>
<td>-</td>
</tr>
<tr>
<td>b) Fixed effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hazard – steepness*</td>
<td>1.009</td>
<td>0.135</td>
<td>&lt;0.001</td>
<td>2.743</td>
</tr>
<tr>
<td>Hazard – size of steep slopes*</td>
<td>0.416</td>
<td>0.118</td>
<td>&lt;0.001</td>
<td>1.517</td>
</tr>
<tr>
<td>Snow hazard – wind slabs</td>
<td>0.654</td>
<td>0.213</td>
<td>0.002</td>
<td>1.923</td>
</tr>
<tr>
<td>Snow hazard – surface hoar farm</td>
<td>0.792</td>
<td>0.254</td>
<td>0.002</td>
<td>2.207</td>
</tr>
<tr>
<td>Terrain hazard – high consequence terrain</td>
<td>0.673</td>
<td>0.209</td>
<td>0.001</td>
<td>1.961</td>
</tr>
<tr>
<td>Ski terrain – cut blocks</td>
<td>-1.634</td>
<td>0.541</td>
<td>0.003</td>
<td>0.195</td>
</tr>
<tr>
<td>Familiarity*</td>
<td>-0.573</td>
<td>0.126</td>
<td>&lt;0.001</td>
<td>0.564</td>
</tr>
<tr>
<td>c) Interaction effects</td>
<td>none</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d) Random intercepts (standard deviations)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ski run</td>
<td>0.399</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Guide</td>
<td>0.903</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Numeric variable. Associated OR is per unit increase.
Figure 23  Effects plots of select predictor variables on *Overall hazard potential* showing a) negative effect of *Familiarity*, b) positive effect of *Steepness*, c) positive effect of *Size of steep slopes*, and d) positive effect of *Cutblocks*.

The random intercepts of two random effect variables are shown in Figure 24. Guide 1 and Guide 12 tended to rate *Overall hazard potential* higher than average and Guide 13 in particular tended to give lower ratings. The SD of the random intercepts for *Guide* (SD = 0.903) was similar to the other perception models, however the SD of the random intercepts for *Run* (SD = 0.399) was much smaller than the random effect of *Run* in the other models.
3.2.4. Overall Guideability

The mean and range in assessments for *Overall guideability* at the two operations are shown in Figure 25, and counts of the binary variables included in this model are in Table 1. Based on the raw assessments, there appeared to be influences of *Familiarity*, *Skiing challenges*, and terrain variables on *Overall guideability* (Figure 25).
Figure 25  Sunflower plots visualizing assessments of *Overall guideability* for each line at a) NEH and b) STHS. This plot can be interpreted identically to Figure 11.
Figure 25  Continued.
Figure 26  Spine plots showing potential relationships between Overall guideability and a) Familiarity, b) Skiing challenges, and c) the presence of Glaciated terrain.

Similar to the OLR model for Overall hazard potential, the presence of several types of skiing terrain had a significant negative effect on Overall guideability, including Extreme alpine faces, Near ridgetop steep slopes, and Glaciated terrain (Table 5). Glaciated terrain was the only type of skiing terrain with a positive effect on Overall guideability at 0.866 (SE 0.243, p < 0.001), which was quite a large estimate relative to the estimates of the other physical terrain characteristics. While the presence of any skiing challenges exhibited a negative effect on Overall guideability (-1.539, SE 0.520, p
none of the individual challenges (e.g., *Traverses/flat sections*, *Mountaineering entrances*, *Wind affected snow*, *Choke points*, and *Dense vegetation*) emerged to have a significant effect. This is likely due to the relatively small sample sizes. *Familiarity* with the ski line had a strong positive effect on the perceived *Overall guideability* at 0.699 (SE 0.138, p < 0.001) per unit increase (Figure 27a). There were no interaction effects in the guideability model.

**Table 5  Overall guideability model summary**

<table>
<thead>
<tr>
<th>Attributes and levels</th>
<th>Estimate</th>
<th>SE</th>
<th>p-value</th>
<th>OR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>a) Intercepts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very Difficult – Difficult</td>
<td>-5.914</td>
<td>0.597</td>
<td>&lt;0.001</td>
<td>-</td>
</tr>
<tr>
<td>Difficult – Neutral</td>
<td>-2.892</td>
<td>0.436</td>
<td>0.854</td>
<td>-</td>
</tr>
<tr>
<td>Neutral – Easy</td>
<td>-0.434</td>
<td>0.419</td>
<td>&lt;0.001</td>
<td>-</td>
</tr>
<tr>
<td>Easy – Very Easy</td>
<td>2.535</td>
<td>0.437</td>
<td>&lt;0.001</td>
<td>-</td>
</tr>
<tr>
<td><strong>b) Fixed effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ski terrain – extreme alpine faces</td>
<td>-1.539</td>
<td>0.520</td>
<td>0.003</td>
<td>0.215</td>
</tr>
<tr>
<td>Ski terrain – near ridgetop steep slopes</td>
<td>-0.375</td>
<td>0.177</td>
<td>0.034</td>
<td>0.687</td>
</tr>
<tr>
<td>Ski terrain – glaciated terrain</td>
<td>0.866</td>
<td>0.243</td>
<td>&lt;0.001</td>
<td>2.377</td>
</tr>
<tr>
<td>Ski challenges</td>
<td>-0.704</td>
<td>0.189</td>
<td>&lt;0.001</td>
<td>0.494</td>
</tr>
<tr>
<td><em>Familiarity</em></td>
<td>0.699</td>
<td>0.138</td>
<td>&lt;0.001</td>
<td>2.012</td>
</tr>
<tr>
<td><strong>c) Interaction effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>none</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>d) Random intercepts (standard deviations)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ski run</td>
<td>0.799</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Guide</td>
<td>1.010</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Numeric variable. Associated OR is per unit increase.
The individual effect of Extreme alpine faces was quite small for all levels of Overall guideability, except for the top level, “Very Easy.” Here, the presence of Extreme alpine faces greatly reduced the probability of a line being assessed as “Very Easy” for guiding (Figure 27b). This is likely due to the relatively small number of lines where Extreme alpine faces was selected as a type of skiing terrain.

The random intercepts of two random effect variables are shown in Figure 28. Guide 2 and Guide 13 tended to rate Overall guideability higher than average and Guide 10 and Guide 12 tended to give lower ratings. The SD of the random intercepts for Guide (SD = 1.010) was similar to the other perception models. The SD of the random intercepts for Run (SD = 0.799) were similar to the other perception models with the exception of the hazard potential model (SD = 0.399).
3.3. Line Use Model (NEH data only)

Line use data consisted of counts of guide GPS tracks on NEH ski lines, which were located between 9 to 29 km from NEH lodge (Distance from lodge). Overall, the six most frequently used lines represented a large proportion of all line use (31%), and there was a steady decline in use among the other lines; Figure 29 shows the individual lines.
sorted by use. The distribution of the response variable appeared consistent with the Poisson assumption (Figure 30).

Figure 29  Histogram showing *Line use* (number of GPS tracks) by individual line.

Figure 30  Histogram showing the distribution of number of times each amount of *Line use* appeared in the dataset (i.e., distribution of the response variable). The bin size is one; each bar represents the number of times that track count occurred in the data set (e.g., there were 7 assessments associated with the line used 271 times).
The distributions of levels for the four perception variables and their relationships with *Line use* gave some insight as to what their effect might be on in this model. Initial plotting indicated potential effects of *General accessibility*, *Overall skiing experience* and *Overall hazard potential* in particular (Figure 31).

**Figure 31**  
Box plots of *Line use* for each level of perceived a) *General accessibility*, b) *Overall skiing experience*, c) *Overall hazard potential*, and d) *Overall guideability*.  

```plaintext
63
```
The fitted line use model was a Poisson mixed-effects model (Table 6). All of the major perception variables were included into the model as numeric predictors. *Overall skiing experience* (0.152, SE 0.012, p < 0.001) and *General accessibility* (0.036, SE 0.011, p < 0.001) were the general perceptions with a positive effect on *Line use*, whereas *Overall hazard potential* (-0.239, SE 0.010, p < 0.001) and *Overall guideability* (-0.053, SE 0.010, p < 0.001) had negative effects. The effects of the individual perception variables are visualized in Figure 32. There were no interaction effects in the line use model.
Table 6  Line use model summary

<table>
<thead>
<tr>
<th>Attributes and levels</th>
<th>Estimate</th>
<th>SE</th>
<th>p-value</th>
<th>e(estimate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>3.766</td>
<td>0.652</td>
<td>&lt;0.001</td>
<td>-</td>
</tr>
<tr>
<td>a) Fixed effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall hazard potential*</td>
<td>-0.239</td>
<td>0.010</td>
<td>&lt;0.001</td>
<td>0.787</td>
</tr>
<tr>
<td>Overall skiing experience*</td>
<td>0.152</td>
<td>0.012</td>
<td>&lt;0.001</td>
<td>1.164</td>
</tr>
<tr>
<td>General accessibility*</td>
<td>0.036</td>
<td>0.011</td>
<td>&lt;0.001</td>
<td>1.037</td>
</tr>
<tr>
<td>Overall guideability*</td>
<td>-0.053</td>
<td>0.010</td>
<td>&lt;0.001</td>
<td>0.949</td>
</tr>
<tr>
<td>Catland</td>
<td>-2.143</td>
<td>0.034</td>
<td>&lt;0.001</td>
<td>0.117</td>
</tr>
<tr>
<td>Operational role – safe and accessible line</td>
<td>0.166</td>
<td>0.018</td>
<td>&lt;0.001</td>
<td>1.181</td>
</tr>
<tr>
<td>Operational role – destination line</td>
<td>-0.147</td>
<td>0.027</td>
<td>&lt;0.001</td>
<td>0.863</td>
</tr>
<tr>
<td>Operational role – time management line</td>
<td>0.141</td>
<td>0.023</td>
<td>&lt;0.001</td>
<td>1.152</td>
</tr>
<tr>
<td>Operational role – open season line</td>
<td>-0.232</td>
<td>0.018</td>
<td>&lt;0.001</td>
<td>0.793</td>
</tr>
<tr>
<td>Operational role – rarely used line</td>
<td>-0.105</td>
<td>0.019</td>
<td>0.002</td>
<td>0.900</td>
</tr>
<tr>
<td>b) Interaction effects</td>
<td>none</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) Random intercepts (standard deviations)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ski run</td>
<td>1.118</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Numerical variable. Associated OR is per unit increase.
Figure 32  Effects plots showing the influence of the four perception variables on Line use.

In the initial model, distance exhibited a non-linear effect on Line use that was strongly negative for lines in runs more than 25 km away from the lodge but not clearly defined for lines closer to the lodge (Figure 33a). A closer examination of the lines on far away runs revealed that the lines with the strongest negative effect were all located in Catland (Figure 33b), an operating zone where runs are accessed by snow cat when weather conditions are not suitable for flying (Figure 34). Hence, the runs in this area are only used during bad weather conditions, which explains the pronounced negative effect observed for lines there. Once a Catland parameter was introduced in the model (-2.143, SE 0.34, p < 0.001; Figure 35), Distance from lodge did not emerge as a significant
parameter anymore. This means that the model did not return evidence that distance from the lodge explicitly affects the use of ski lines located between 9 and 29 km from the lodge. This is not overly surprising as the distances within the Promised Land operating zone are relatively short. However, I would expect distance to have a substantial influence on Line use beyond neighborhood of the lodge and home drainage.

Figure 33 Scatter plots visualizing the distance from the lodge of a) all NEH runs, and b) Catland runs highlighted. Points jittered to prevent overplotting.
Figure 34  Map displaying the locations of Catland runs (highlighted in green) as related to the others at NEH. Dot colors indicate increasing distance from the lodge.

Figure 35  Effect plot showing the influence of a line being in Catland (y-axis on exponential scale).

The individual operational roles had varying effects on Line use. Safe and accessible line and Time management line had a positive effect on mean Line use, and Destination line, Open season line, and Rarely used line had a negative effect in this model. This indicates that these roles influence guides’ decisions, as they are attracted
to lines safe for access that improve operational efficiency but avoid lines that may be isolated from a circuit, require bomb-proof conditions, or are used less for other reasons.

The line use model only had a random effect of Run which displays how certain runs saw more or less Line use than others after controlling for the fixed effects (Figure 36). For example, Laguna and Sun Dog tended to be used less overall, and Chupete and Pacha Mama were used more. These four runs are all in Catland, which means that the strong negative effect of the Catland predictor is partially offset or further enhanced by the random effect for these runs. Because the OR of skiing a line in Catland is 0.117 and the positive shift in the random intercept for Chupete is slightly larger than 10, lines on this run are not actually used much more than other lines at NEH. By the same concept, the Catland lines with negative shifts in their random intercepts (Laguna and Sun Dog) are used substantially less frequently than other lines at NEH after controlling for the fixed effects.

Figure 36 Random effect of Run in the line use model.
Chapter 4.

Discussion

The objective of this study was to introduce a new terrain characterization framework and provide comprehensive quantitative insight into the factors affecting terrain choices in professional guides. The results of the quantitative analysis highlight that guides’ terrain perceptions and subsequent terrain choices are affected by a wide range of factors pertaining to access, hazard, and benefit considerations, which ultimately validates the framework’s ability to describe terrain. The following sections summarize the results and extract the main lessons of this research.

4.1. Factors Affecting Terrain Choices

4.1.1. Line Use Model

As a culmination of all the factors used in the terrain survey, the line use model comprehensively quantifies for the first time how terrain decisions are trade-offs between feasibility of use (General accessibility), physical hazards and how they can be managed (Overall hazard potential and Overall guideability), the potential benefits that a ski line can provide to the skiing experience of guests (Overall skiing experience), and maintaining an efficient operation (Operational roles). The specific trade-offs contributing to these perceptions result from the terrain characteristics that work to either improve or hinder a guide’s ability to safely and efficiently provide the desired skiing product to guests (i.e., achieve their operational objective). The emergence of these trade-offs in the models is consistent with descriptions of decision-making practices in professional heli-skiing (Israelson, 2015; Northern Escape Heli-Skiing, 2019), and they show how guides need to focus on more than just hazard when making their terrain choices. While the existing literature and manuals in avalanche risk management focus on terrain factors that are important for deciding how to use terrain safely in the backcountry (e.g., Association of Canadian Mountain Guides, 1999; Tremper, 2008), heli-ski guides clearly weigh more than just hazard considerations (Overall hazard potential) as they shape the product they offer their guests. Furthermore, the balance that emerged between Overall skiing experience and Overall hazard potential is consistent with McClung’s (2002)
description of the ORB, which highlights that guide decisions need to avoid both excessive exposure to avalanche hazard to avoid accidents and excessive conservatism that would result in missed opportunities for good skiing.

Ultimately, the realism of the line use model confirms that the terrain characterization framework contains meaningful variables that guides consider when shaping their perceptions of terrain and when making their choices. The line use model represents the link between terrain perceptions and behavior because the perception variables emerged as influential predictor variables. Since the perception variables were modeled using terrain characteristics in a way that is meaningful to guides and their choices, the line use model provides quantitative proof that the framework successfully captures terrain characteristics that relate to guide perceptions, which lead to decisions. This has important implications for future research aiming to better understand avalanche risk management through the examination of revealed terrain preferences in professional guides. The terrain framework presented in this study identifies a whole suite of new terrain variables that are related to decision-making in the backcountry but have not yet been identified or clearly defined. Studies can now utilize the variables provided by the framework to explicitly examine how choices are influenced by terrain characteristics beyond hazard related features. Furthermore, the framework offers terminology for describing more holistic terrain characteristics (e.g., skiing experience, surface hoar farm) that cannot be captured by easily extractable terrain measures (e.g., slope angle) but may explicitly relate to how people make their terrain-use choices. Since the terminology included in the framework was built on established language used in the guiding community, the present approach is especially applicable to research examining guide behavior.

4.1.2. Perception Models

Similar to the way the line use model validates the perception variables in the framework, the four perception models describe the link between how guides perceive terrain from a mechanized skiing perspective and the terrain’s physical characteristics. With the framework, these models describe variables well-known in the avalanche community as well as previously unexplored factors affecting terrain choices using new and meaningful terminology.
As expected, variables that have traditionally been included in descriptions of avalanche terrain emerged as significant contributors in the final models. Slope steepness, exposure to avalanche hazard, and terrain traps are well-known dangers in the backcountry that must be considered for safe travel (McClung and Schaerer, 2006; Tremper, 2008), and these very factors (Slope steepness, Size of steep slopes, and High consequence terrain) were shown to play an important role in the way guides perceive the Overall hazard potential of skiing terrain. Concern with overhead avalanche hazard is another anticipated aspect of terrain perception in guides. The negative effect of Large cycle OH hazard above pickups on General accessibility shows how guides consider overhead exposure above pickups when considering if a line is appropriate for skiing. Hence, the results presented in this study connect well to the existing scientific literature on avalanche terrain.

However, the perception models also uncover new factors contributing to how guides perceive the hazard potential of skiing terrain. Since wind slabs and persistent weak layers routinely generate elevated avalanche hazard (Statham et al., 2018; Tremper, 2008), it is not surprising to see that slopes Prone to wind slabs and Surface hoar farms had a negative effect on the perceived Overall hazard potential. While the magnitude of the effect of these snow hazard variables was smaller than Slope steepness or Size of steep slopes, which are both more fundamental terrain characteristics, the impact is still substantial. This means that these factors play an important role in the way guides perceive the hazard potential of terrain, and research projects relying solely on terrain characteristics extracted from DEM data will miss these more intangible albeit important terrain characteristics.

The patterns of significant terrain attributes in the hazard potential and guideability models show some similarities to the original ATES model (Statham et al., 2006). The ATES severity ratings use some of the same general terrain features that emerged as predictor variables in my analysis, such as slope steepness, the presence of avalanche paths and exposure to start zones. Interestingly, however, while glaciated terrain is a decisive characteristic for the “complex terrain” category in the original ATES system, ski lines with this terrain feature were perceived to be more easily guidable in the present analysis. While this result contradicts the original ATES terrain class definitions, it is consistent with the general sentiment in the avalanche safety community that glaciation might not be a meaningful parameter for avalanche terrain classification.
Hence, the next version of the ATES classification definitions, which is current in development, will not include glaciation as a parameter anymore (Grant Statham, personal communication, March 2019).

It is important to note that the ATES model currently used in automated terrain zoning projects only includes a limited number of terrain features (e.g., forest density, slope angle, slope shape, and start zone density) that are easily available from DEMs (Campbell et al., 2012; Campbell and Gould, 2013). While these automated zoning systems can efficiently map terrain, they currently do not incorporate some of the “higher-level” terrain characteristics from the original ATES class definitions that are difficult to quantify but emerged as significant contributors in this analysis (e.g., consequential terrain, amount of exposure, slope shape). The avalanche terrain maps recently developed by Harvey et al. (2018a) offer a promising new approach for addressing this shortcoming. These authors expanded the automated terrain zoning process by combining DEM data with the avalanche simulation model RAMMS::EXTENDED (Bartelt et al., 2012) to produce avalanche terrain maps with continuous-scale ratings of the avalanche exposure severity. These maps aim to display more of the relevant information backcountry travelers use to make choices, such as size of potential release areas, sensitivity to remote triggering, avalanche runout, and potential consequences. All of these factors emerged as significant contributors in the overall hazard potential model, which clearly confirms that the features presented on the avalanche terrain maps developed by Harvey et al. (2018a) are decision-relevant. Possible contributions of the terrain characterization framework to this general line of research are a) to highlight what type of terrain features are relevant to guides for inclusion in terrain maps, and b) to collect quantitative information on more holistic terrain features to validate algorithms that can derive them from DEMs.

The skiing experience model explicitly quantifies factors that contribute to a good skiing experience as perceived by the guides for the first time. My model shows that Extreme alpine faces, Big vertical, Fall line skiing, Deep powder and Glaciated terrain were perceived to be the most important factors contributing to a high-quality skiing experience among the guides participating in this study. These variables are consistent with some of the key experiences guests hope to encounter while heli-skiing; glaciated terrain and extreme alpine facers are iconic attractions in the heli-ski industry. Scenic views, big vertical, and long, fall-line skiing are special experiences that mechanized
skiing provides best. These features have been well understood by guides, and their quantitative inclusion in the skiing experience model identifies them as meaningful terrain variables that can help operations keep records of the types of skiing terrain available in their tenure region. While I expect the ratings of Overall hazard potential at different mechanized skiing operations to exhibit considerable consistency, I suspect the assessments of Overall skiing experience to be more variable as this is derived more from the nature of the skiing product offered by a particular operation (which can be quite different between operations). The skiing experience model provides novel insight into the attractive forces that motivate guides to select skiing terrain.

4.1.3. Notable Observations

The analysis produced some unexpected and potentially counter-intuitive results. The positive effect of Skiing difficulty on Overall skiing experience (Figures 18b) is particularly interesting because I initially assumed that guides might associate difficult skiing with a reduced skiing experience for guests. However, exciting and elevated skiing experiences most likely exist in steep and technical terrain (especially from guides’ perspectives due to their skill), which is also where they view the Skiing difficulty to be higher for guests. While this natural collinearity is partially controlled for by terrain variables included in the overall skiing experience model, the natural relationship between guide perception of quality skiing and technical terrain is strong enough to stand alone.

Another notable observation is that the knowledge of, or personal experience with, a helicopter or avalanche incident did not significantly affect how the participating guides perceived the accessibility or friendliness of ski lines. Klein (1998, 2004) and Slovic et al. (2004) describe how significant personal experiences are encoded as emotional responses that then manifest as the affect heuristic, which influences the subconscious decision-making process in future environments similar to those past circumstances. Therefore, it seemed reasonable to assume that experiences with potentially life-threatening incidents would have a measurable negative effect on guides’ perceptions. However, my models did not confirm this hypothesis, and I see two factors potentially contributing to incidents not emerging as significant variables in my models. First, there is a natural collinearity between incidents and frequency of use; ski lines with known incidents are also more familiar to the guides, which exhibits a strong relationship
with friendlier perceptions. Second, the relatively low frequencies of incident awareness information in the data set prevented the generation of meaningful parameter estimates for the influence of incidents that overcome the more dominant effect of familiarity.

4.1.4. Variability Among Runs

The random effect of Run in the four perception models shows that the hazard potential model most effectively captured the run-specific variability in the data set caused by differences among runs. The SD of the intercepts of the Run random effect variable for the hazard potential model (SD = 0.366) was roughly half what it is in the other three perception models (General accessibility: SD = 1.023, Overall skiing experience: SD = 0.983, and Overall guideability: SD = 0.799). The residual by-run variance in the three models is considerably larger, which means that the terrain characteristics included in these models are unable to describe the observed variability as well as in the overall hazard potential model. There may be additional factors not covered by the survey that play a role in how guides perceive General accessibility, Overall skiing experience, and Overall guideability, or the response options for the questions included in the survey might have not been sufficient. However, given that hazard characteristics have been the primary means to describe avalanche terrain to-date, it is no surprise that the overall hazard potential model performed the best. Guides have been trained with terrain and avalanche hazards in mind, so the community is most equipped to discuss and communicate these hazard features. This highlights that more work is required to systematically describe those characteristics of skiing terrain unrelated to hazard.

Runs with unusually large random intercepts (positive or negative) can help identify runs that stand out, particularly in the line use model (Figure 38). For example, the two runs with the most negative random intercepts (Sun Dog and Laguna) are both in Catland at NEH, the run cluster used for cat skiing when weather is too poor for helicopters. Because of its unique role, Catland runs are used very differently than more typical runs. While the Catland variable emerged as a negative predictor of Line use, one Catland run, Chupete, had the most positive random intercept of all NEH runs. It would be worth investigating why lines on Chupete see so much compared to the other Catland runs. The random effect of Run offers a starting point for operational
management and terrain research by pointing to standout runs than require further investigation.

### 4.2. Differences Among Operations

The perception models presented in this study revealed little evidence of differences in the way guides perceive ski lines between NEH and STHS. Only three interaction effects emerged from the modeling process, and they only exist in the skiing experience and general accessibility models. There were no interaction effects in the hazard potential and guideability models.

The only interaction effect that emerged in the skiing experience model was STHS guides’ dislike for *Planar slopes* relative to NEH’s guides’ skiing preferences, which may just be a result of the different nature of the terrain at the two operations. The two interaction effects between the landing characteristics (i.e., *Best referenced landing* and *Low gross weight* landing) and *Operation* in the accessibility model may be directly related to the types of helicopters the two operations employ to transport guests. For the most part, NEH flies smaller machines than STHS, with maximum group sizes at four to six guests. STHS, on the other hand, can transport up to three groups of 11 guests each using only their Bell 205. STHS’s Bell 205, being capable of carrying twice the guests of the other machines, is most likely the reason for the negative interaction effect of *Low gross weight landings* at STHS on *General accessibility*. This may also be why there was only one observation of a *Low gross weight landing* on a line at NEH. The larger effect of *Best referenced landing* on perceived accessibility at STHS might also be due to the Bell 205, which might require better visual cues on approach in order to be able to access a landing.

The lack of interaction effects with *Operation* in the hazard potential model means that on average guides of both operations perceive the same types of ski lines at similar values of hazardousness (i.e., unfriendliness). This is interesting because NEH and STHS are located far apart in different snow climates. NEH operates in the maritime snow climate of the northern Coast Mountains, whereas STHS is situated in the central Columbia Mountains, which have a transitional snow climate. It seems reasonable to assume that the same terrain might be perceived as less friendly in a transitional snow climate than a maritime snow climate where the snowpack is generally more stable and
instabilities do not persist as long (McClung and Schaerer, 2003). However, the lack of operation-related interaction effects indicates that the way guides perceive terrain is predominantly shaped by terrain features independent of the characteristics of their local operation. This is a favorable result as it highlights consistency in the perception of terrain hazards among the guiding community. A similar argument can be made for the lack of operation-related interaction effects in the guideability model. Ultimately, these results are encouraging from a management perspective as they mean that operators can expect the same terrain hazard perception from guides regardless of their operational backgrounds. However, it is important to remember that this conclusion only has limited support as the present study only included assessments from guides of two operations.

I expected perceptions of good skiing to differ more substantially between operations because the nature of the skiing product often varies from operation to operation. I attribute the lack of additional interaction effects mainly to the relatively small sample size of STHS assessments. Furthermore, a comparison between two mechanized skiing operations that market more distinctly different skiing products (e.g., high-alpine skiing at NEH versus steep tree skiing at CMH Galena Lodge) might produce more obvious differences. These results could help operations managers assess how their team views the product they advertise and ensure that the team is well calibrated to the types of experiences they want to provide guests from a management perspective.

4.3. Differences Among Guides

While my analysis did not show major differences between operations, it did reveal some trends in the way guides assess terrain.

I initially suspected that guide characteristics would play a substantial role in terrain perception due to individual personal differences and the impact those might have on the way guides evaluate their environment. A guide’s level of Familiarity with a ski line consistently appeared as a major influence on guide perception; it had a positive effect on Overall skiing experience and Overall guideability, and a negative effect on Overall hazard potential. This appearance of Familiarity in three of the perception models marks it as one of the most widely influential features, and the only main guide characteristic to have an effect on the perception models. While familiarity is naturally
colinear with the quality of a line (i.e., better lines are skied more frequently), the perception models control for this association by also including individual terrain characteristics that make ski lines desirable. This strengthens the argument that guides in general rate a ski line they are familiar with as a better skiing experience, friendlier, and more easily guideable than a colleague less familiar with the same line.

The negative relationship between *Familiarity* and *Overall hazard potential* is a particularly important result. On one side, familiarity is an inherently positive concept that results from experience and knowledge, which can generate comfortable affective states in guides while considering terrain they ski often. However, on the other side, it is important to recognize that familiarity has the potential to reduce vigilance. McCammon’s (2004) first heuristic trap among recreationists is inappropriately underestimating the avalanche hazard on a slope due personal familiarity with that slope. Guyn (2016) called the “misappropriation of terrain” the top common misstep in avalanche terrain among professionals, and it may be that even guides are susceptible to the familiarity trap when attempting to match terrain to current conditions. Increasing guides’ awareness of familiarity’s potential subconscious influences might help guides to be more self-aware in decision-making circumstances where familiarity might be influencing an otherwise objective evaluation.

Somewhat surprising, no other personal characteristics included in the survey (e.g., *Home snow climate*, *Years guiding at operation*, *Guide operational role*, *Gender*) emerged as significant explanatory variables in the perception models. This means that none of these variables were able to explain the observed variability among guides that is currently captured in the random effect of Guide in the different perception models. The variances of the Guide random intercepts were similar for all four models (*General accessibility*: SD = 1.041, *Overall skiing experience*: SD = 1.003, *Overall hazard potential*: SD = 0.859, and *Overall guideability*: SD = 0.799), and I attribute the lack of guide characteristics to the relatively small number of guides who participated in this study. A larger sample of guides with different backgrounds and experience levels may produce more insight into the effect of personal differences on terrain perceptions. While the random effect cannot provide insight into the underlying reasons for the observed variability in guide perceptions, it is informative for guides and operations to at least have a measure of the magnitude of the perception variability within their team.
4.4. Limitations of Study

The sample size of this study was the main source of its limitations. This affected the results in three ways. First, the fact that only two operations participated in the study made it difficult to draw meaningful conclusions about differences in terrain perceptions among heli-ski operations in general. I do not expect the overall skiing experience model to be generalizable to other operations because many heli-skiing companies advertise very different products. Hence, their relationship between terrain variables and the *Overall skiing experience* is expected to be different. Furthermore, the line use model presented in this study only included line use data from NEH, so the link between perception and behavior is derived from NEH only. Second, the relatively small number of participating guides prevented an in-depth examination of the effect of personal differences on terrain perceptions. For example, since only one female guide participated in the survey, it was impossible to examine the effect of gender on terrain perceptions. Finally, the small sample also meant that some of the more unique terrain characteristics only rarely appeared in the analysis dataset, which prevented me from reliably assessing their influence on the perception models.
Chapter 5.

Conclusion

This research introduced a novel terrain characterization framework that comprehensively describes the nature of ski lines in mechanized skiing beyond hazard characteristics. The framework is founded upon five themes of terrain characteristics that influence the way guides make choices in an operational environment: access, skiing experience, usability, hazard potential, and mitigation. The terrain variables included in the framework are structured around information that is actually relevant to decision-making, and they capture information that ranges from objective information about the presence of specific terrain features to the subjective perceptions about the overall nature of terrain.

The framework was implemented as an online survey to gather ski line assessments from heli-ski guides at two operations in B.C., Canada. The analysis of the survey data produced four perception models that quantitatively link guides’ terrain perceptions (General accessibility, Overall skiing experience, Overall hazard potential, and Overall guideability) to ski line features meaningful for guiding. The behavioral line use model describes how these general perceptions combine to ultimately influence line use, which is the first description of the perception-behavior link in avalanche terrain. The emergence of logically sound terrain variables in these models confirms that the framework captures relevant terrain information in a meaningful way.

The introduction of new variables describing non-hazard related ski line features fill the knowledge gap between avalanche hazard and terrain-use choices that currently exists in the avalanche research community. These new variables offer new avenues to analyze their decision-making in avalanche terrain in a more comprehensive way. Future studies on terrain preferences of professional guides now have a framework and terminology to collect information on critical, non-hazard related decision factors. This will lead to a more holistic understanding of the effect avalanche hazard has on guide terrain choices amidst all the factors they consider in a mechanized operational environment. Another potentially interesting avenue of research would be to compare qualitative terrain perceptions to measurable terrain attributes to better understand
human perception of avalanche terrain. A good example of this type of research would be to link the qualitative terms for slope steepness to distributions of incline measurements from DEMs. The information collected with the present terrain framework can also help identify more complex and holistic terrain features that have been difficult to characterize in the past. Whereas avalanche start zones and areas with overhead hazard that have been identified by guides can be used to validate existing algorithms that automatically identify these areas (e.g., Harvey et al., 2018b), guide knowledge of other holistic terrain characteristics (e.g., surface hoar farms) can assist in the development on new algorithms for identifying these types of features in DEMs. In the long-term, this type of research will facilitate the development of more sophisticated algorithms for automated avalanche terrain mapping.

The terrain characterization framework and survey also offer several benefits to mechanized operations and guides by offering an opportunity to assess the alignment of perspectives within guiding teams. The by-guide and by-run random effects offer new resources for operations managers to characterize the views among the guiding team as well as identify stand-out runs. This is an important starting point for investigations into how an operation runs and improvements that can be made from a business perspective (e.g., discovering runs with the highest economic potential or discovering runs that may be used out of habit). Guides noted that completing the survey was a useful exercise in self-reflection and assessing their own perspectives.

Finally, the survey’s capability for extensive knowledge capture can be a useful tool for mentorship and communication among operations. The framework and survey are a method for operations to gather more meaningful information regarding the terrain they use. Since the terrain survey is derived directly from the heli-skiing industry, the comprehensive run summaries generated by completion of the survey offer a terrain catalogue with specific, operation-relevant terrain features that can improve mentorship of new guides. The current version of the online survey is designed to collect terrain data from individual guides, but the website can easily be redesigned to present the information back to the guiding team in a more effective way.
References


Appendix

Terrain Characterization Survey

What follows are a series of tables displaying all questions in the terrain characterization survey, organized by the five themes of the framework (Access, Skiing Experience, Usability, Hazard Potential, and Mitigation), general questions pertaining to the entirety of a run, and guide personal background information. The left column indicates each attribute by name, the data classification information (binary, categorical, ordinal, or numeric), and the level at which the question was applied in the survey (for an entire run, for each line on a run, for each elevation band on each line, or for each guide). The second column lists the specific phrasing of each question as displayed on the website, and the third column lists all potential responses.

Table A 1  General questions

<table>
<thead>
<tr>
<th>Attribute (data type – level)</th>
<th>Question</th>
<th>Response Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conflict (categorical – run)</td>
<td>After a new snowfall, how much time do you typically have before this run becomes unusable due to conflicts with other users?</td>
<td>• No conflict • 1 day • A few days • Approx. 1 week • Only occasionally</td>
</tr>
</tbody>
</table>

Table A 2  Access

<table>
<thead>
<tr>
<th>Attribute (data type – level)</th>
<th>Question</th>
<th>Response Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>General accessibility (ordinal – run)</td>
<td>How do generally feel about the accessibility of this ski line when flying conditions are good enough to reach its run cluster?</td>
<td>1. Even if I can access this run cluster, flying conditions need to be perfect to consider this run (Perfect) 2. Even if I can access this run cluster, conditions need to line up to make this work (Line up) 3. It is often possible to make this work when I can access this run cluster (Possible) 4. I can almost always get to this line when I can access this run cluster (Always)</td>
</tr>
<tr>
<td>Attribute (data type – level)</td>
<td>Question</td>
<td>Response Levels</td>
</tr>
<tr>
<td>------------------------------</td>
<td>----------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Best referenced landing (ordinal – line)</td>
<td>What is the flight approach to the best referenced landing of this ski line?</td>
<td>1. Minimally or not referenced (e.g., wide open landing) 2. Reasonably referenced (e.g., rocks, few trees) 3. Well referenced</td>
</tr>
<tr>
<td>Landing flight hazards (binary options – line)</td>
<td>Do the landing(s) of this ski line have any outstanding flight hazards?</td>
<td>• Low gross weight landing(s) • Challenging under strong winds • Backward landings not possible (e.g., during outflow conditions) • Other text field</td>
</tr>
<tr>
<td>Pickup flight hazards (binary options – line)</td>
<td>Do the pickup(s) of this ski line have any outstanding flight hazards?</td>
<td>• Minimal or no reference for pilots • Low gross weight pickup(s) • Susceptible to valley fog • Exceptionally susceptible to blowing snow (‘snowballing’) • Avalanche overhead hazard during regular cycles • Avalanche overhead hazard during large cycles • Common presence of triggers for overhead avalanche hazards • Other text field</td>
</tr>
<tr>
<td>Flying incidents (ordinal – line)</td>
<td>Are you aware of any flying incidents or near misses on this ski line?</td>
<td>1. No, I am not aware of any flying incidents or near misses on this ski line 2. Yes, I am aware of flying incidents or near misses on this ski line 3. Yes, I have personally been involved in flying incidents or near misses on this ski line</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table A 3 Skiing Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attribute (data type – level)</td>
</tr>
<tr>
<td>Skiing terrain (binary options – elevation band)</td>
</tr>
<tr>
<td>Attribute (data type – level)</td>
</tr>
<tr>
<td>-------------------------------</td>
</tr>
</tbody>
</table>
| Skiing difficulty (ordinal – line) | What is the skiing difficulty level of this line for guests when conditions are good? | 1. Easy  
2. Moderate  
3. Challenging |
| Skiing challenges (binary options – line) | Does this ski line have any challenges that negatively affects the guest experience? | 1. Extended traverses or flat sections (e.g., not suitable for snowboarders)  
2. Entrances requiring mountaineering skills  
3. Commonly poor skiing conditions due to wind affected areas  
4. A choke point (e.g., funnel, creek, gully) that forces skiers through existing tracks  
5. Dense vegetation  
6. Other text field |
| Overall skiing experience (ordinal – line) | When conditions are good, what is your opinion of the overall skiing experience that this ski line offers? | 1. Poor (happy to move on)  
2. Fair (not bad skiing)  
3. Good (a good product)  
4. Very good (this is why guests come back for more)  
5. Exceptional (life changing mountain experience) |
### Table A 4  Usability

<table>
<thead>
<tr>
<th>Attribute (data type – level)</th>
<th>Question</th>
<th>Response Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fresh tracks (numeric – line)</td>
<td>What is the approx.. number of fresh tracks this run can handle in total before it is completely tracked out?</td>
<td>• Text box for number of fresh tracks when Line 1 is open&lt;br&gt;• Text box for number of fresh tracks when Line 1 and Line 2 are open together&lt;br&gt;• Text box for number of fresh tracks when Line 1, Line 2, and Line 3 are all open</td>
</tr>
<tr>
<td>Reset previous tracks (numeric – run)</td>
<td>How much new snow is typically required to reset previous tracks on this ski run?</td>
<td>1. 10 cm of new snow&lt;br&gt;2. 20 cm of new snow&lt;br&gt;3. 30 cm of new snow&lt;br&gt;4. 40 cm of new snow</td>
</tr>
<tr>
<td>Freezing level elevation (numeric – run)</td>
<td>To what elevation do freezing levels need to rise for this run to become undesirable because you are running out of meaningful pickup options to avoid poor skiing?</td>
<td>• Text box for number of meters above sea level when run becomes unusable</td>
</tr>
<tr>
<td>Operational role (binary options - line)</td>
<td>Does this run have a particular operational role(s) in your program when the ski line is open?</td>
<td>• Safe and accessible (under almost all conditions)&lt;br&gt;• Signature run (defines your operation)&lt;br&gt;• Destination run (objective of a circuit)&lt;br&gt;• Bread and butter run (high efficiency production run)&lt;br&gt;• Time management run (can be used to keep busy for a while, e.g., during fuel run)&lt;br&gt;• Key jump run (makes a circuit work)&lt;br&gt;• Regular lunch run&lt;br&gt;• Not preferred run (only considered if running out of options for reasonable skiing)&lt;br&gt;• Extreme run (only considered under bombproof conditions&lt;br&gt;• Critical bad weather run&lt;br&gt;• Not frequently visited but important under special circumstances</td>
</tr>
<tr>
<td>Sun exposure (ordinal – line)</td>
<td>How much sun exposure can this ski line handle on March 1 before a sun crust forms and it becomes undesirable for skiing?</td>
<td>1. Sun crusts are seldom&lt;br&gt;2. Yes, I am aware of flying incidents or near misses on this ski line&lt;br&gt;3. Yes, I have personally been involved in flying incidents or near misses on this ski line</td>
</tr>
<tr>
<td>Attribute (data type – level)</td>
<td>Question</td>
<td>Response Levels</td>
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<td>-------------------------------</td>
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</tbody>
</table>
| Steepness (ordinal – elevation band) | What is the steepness of the most serious slopes on this ski line? | Alpine  
1. Gentle  
2. Moderately steep  
3. Moderate with steep pitches  
4. Sustained steep  
Treeline  
1. Gentle  
2. Moderately steep  
3. Moderate with steep pitches  
4. Sustained steep  
Below Treeline  
1. Gentle  
2. Moderately steep  
3. Moderate with steep pitches  
4. Sustained steep |
| Size of steep slopes (ordinal – elevation band) | If ‘moderately steep’ or ‘steep,’ what is the size of the sufficiently steep traveled avalanche slopes on this ski line? | Alpine  
1. No avalanche slopes  
2. Single smaller avalanche slope  
3. Multiple smaller avalanche slopes  
4. Large avalanche slope(s)  
Treeline  
1. No avalanche slopes  
2. Single smaller avalanche slope  
3. Multiple smaller avalanche slopes  
4. Large avalanche slope(s)  
Below Treeline  
1. No avalanche slopes  
2. Single smaller avalanche slope  
3. Multiple smaller avalanche slopes  
4. Large avalanche slope(s) |
| Avalanche terrain hazards (binary options – elevation band) | Does this ski line have any standout avalanche related terrain hazards | Alpine  
- Avalanche overhead hazard on regular cycles  
- Avalanche overhead hazard during large cycles only  
- Common presence of triggers for overhead avalanche hazard  
- Lack of surface roughness  
- Unavoidable unsupported terrain shapes  
- High consequence terrain when caught  
- Slopes that tend to retain hzd for human triggering  
- Other text field |
<table>
<thead>
<tr>
<th>Attribute (data type – level)</th>
<th>Question</th>
<th>Response Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treeline</td>
<td></td>
<td>Avalanche overhead hazard on regular cycles</td>
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<tr>
<td></td>
<td></td>
<td>Avalanche overhead hazard during large cycles only</td>
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<tr>
<td></td>
<td></td>
<td>Common presence of triggers for overhead avalanche hazard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lack of surface roughness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unavoidable unsupported terrain shapes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High consequence terrain when caught</td>
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<tr>
<td></td>
<td></td>
<td>Slopes that tend to retain hzd for human triggering</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other text field</td>
</tr>
<tr>
<td>Below Treeline</td>
<td></td>
<td>Avalanche overhead hazard on regular cycles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Avalanche overhead hazard during large cycles only</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Common presence of triggers for overhead avalanche hazard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lack of surface roughness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unavoidable unsupported terrain shapes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High consequence terrain when caught</td>
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<tr>
<td></td>
<td></td>
<td>Slopes that tend to retain hzd for human triggering</td>
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<tr>
<td></td>
<td></td>
<td>Other text field</td>
</tr>
<tr>
<td>Avalanche snow conditions</td>
<td></td>
<td>Alpine</td>
</tr>
<tr>
<td>(binary options – elevation band)</td>
<td></td>
<td>Prone to wind slabs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thin snowpack</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable snowpack/cross-loading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other text field</td>
</tr>
<tr>
<td>Treeline</td>
<td></td>
<td>Prone to wind slabs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface hoar farm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thin snowpack</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable snowpack/cross-loading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other text field</td>
</tr>
<tr>
<td>Below Treeline</td>
<td></td>
<td>Surface hoar farm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thin snowpack</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable snowpack/cross-loading</td>
</tr>
</tbody>
</table>

Is this ski line particularly known for avalanche hazard promoting snow conditions?
<table>
<thead>
<tr>
<th>Attribute (data type – level)</th>
<th>Question</th>
<th>Response Levels</th>
</tr>
</thead>
</table>
| Non-avalanche hazards (binary options – elevation band) | Are there non-avalanche related hazards that stand out on this ski line? | Alpine  
- Isolated crevasse hazard  
- Widespread, unavoidable crevasse hazard  
- Cornices directly affecting ski line  
- Other text field  
Treeline  
- Cornices directly affecting ski line  
- Tree well hazard  
- Open creeks, vent holes, rock crevasses  
- Particularly challenging for rescues or finding a lost skier  
- Other text field  
Below Treeline  
- Cornices directly affecting ski line  
- Tree well hazard  
- Large tree bombs  
- Open creeks, vent holes, rock crevasses  
- Particularly challenging for rescues or finding a lost skier  
- Other text field  
| Overall friendliness (ordinal – elevation band) | In terms of hazards, what is your sense of the overall friendliness of the terrain on this ski line? | Alpine  
1. Very unfriendly  
2. Unfriendly  
3. Neither  
4. Friendly  
5. Very friendly  
Treeline  
1. Very unfriendly  
2. Unfriendly  
3. Neither  
4. Friendly  
5. Very friendly  
Below Treeline  
1. Very unfriendly  
2. Unfriendly  
3. Neither  
4. Friendly  
5. Very friendly |
### Table A 6  Mitigation

<table>
<thead>
<tr>
<th>Attribute (data type – level)</th>
<th>Question</th>
<th>Response Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skier traffic (categorical – line)</td>
<td>Is this ski line suitable for mitigating avalanche hazard by maintenance with skier traffic?</td>
<td>• No, not suitable&lt;br&gt;• Yes, it would be possible, but we don’t actually do it&lt;br&gt;• Yes, we actively maintain this ski line with skier traffic</td>
</tr>
<tr>
<td>Self-stabilization (categorical – line)</td>
<td>Is it common for critical slopes on this ski line to self-stabilize through natural avalanching?</td>
<td>• No, avalanche hazard tends to persist on critical avalanche slopes on this ski line&lt;br&gt;• Yes, critical avalanche slopes on this ski line commonly self-stabilize</td>
</tr>
<tr>
<td>Overall guideability (ordinal – line)</td>
<td>What is your personal opinion of the overall ‘guide-ability’ of this ski line?</td>
<td>1. Very difficult (requires detailed instructions and a close eye on the guest)&lt;br&gt;2. Difficult&lt;br&gt;3. Moderately difficult&lt;br&gt;4. Easy&lt;br&gt;5. Very easy (terrain naturally leads guests to the right line)</td>
</tr>
<tr>
<td>Guiding incidents (categorical – line)</td>
<td>Are you aware of any guiding incidents or near misses on this ski line?</td>
<td>• No, I am not aware of any guiding incidents or near misses on this ski line&lt;br&gt;• Yes, I am aware of guiding incidents or near misses on this ski line&lt;br&gt;• Yes, I have personally been involved in guiding incidents or near misses on this ski line</td>
</tr>
</tbody>
</table>

### Table A 7  Personal Guiding Background

<table>
<thead>
<tr>
<th>Attribute (data type – level)</th>
<th>Question</th>
<th>Response Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (categorical – guide)</td>
<td>What is your gender?</td>
<td>• Male&lt;br&gt;• Female&lt;br&gt;• Other text field</td>
</tr>
<tr>
<td>What is your age? (numeric – guide)</td>
<td>What is your age?</td>
<td>Numeric text field</td>
</tr>
<tr>
<td>Guiding credential (categorical – guide)</td>
<td>What is your highest professional guiding credential?</td>
<td>• IFMGA/ACMG Full Mountain Guide&lt;br&gt;• ACMG Full Ski Guide&lt;br&gt;• ACMG Assistant Ski Guide&lt;br&gt;• Canadian Ski Guide Level 3&lt;br&gt;• Canadian Ski Guide Level 2&lt;br&gt;• Canadian Ski Guide Level 1&lt;br&gt;• Other text field</td>
</tr>
<tr>
<td>Attribute (data type – level)</td>
<td>Question</td>
<td>Response Levels</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------</td>
<td>----------------</td>
</tr>
<tr>
<td>Guiding experience (numeric – guide)</td>
<td>How many winters of guiding experience do you have in mechanized skiing?</td>
<td>Numeric text field</td>
</tr>
<tr>
<td>Operation experience (numeric – guide)</td>
<td>For how many winters have you guided at your current operation (Northern Escape Helicopters/Selkirk Tangiers Heli Skiing)?</td>
<td>Numeric text field</td>
</tr>
</tbody>
</table>
| Professional role (categorical – guide) | What is your highest operational role at your current operation (Northern Escape Helicopters/Selkirk Tangiers Heli Skiing)? | • Owner  
• Operator  
• Operations Manager  
• Lead Guide  
• Guide  
• Other text field |
| Home snow climate (categorical – guide) | In which snow climate did you mainly learn your guiding skills? | • Maritime snow climate (e.g., Coast Mountains)  
• Transitional snow climate (e.g., Columbia Mountains)  
• Continental snow climate (e.g., Rocky Mountains) |
| Primary snow climate (categorical – guide) | Looking at your entire guiding career until now, in which snow climate have you spent most of your guiding time? | • Maritime snow climate (e.g., Coast Mountains)  
• Transitional snow climate (e.g., Columbia Mountains)  
• Continental snow climate (e.g., Rocky Mountains) |
| Mentorship (ordinal – guide) | During your first decade of your guiding experience, what was your access to mentorship from acknowledged experts in your field? | 1. None  
2. Limited to formal training courses (e.g., ACMG exams)  
3. Ongoing guidance from immediate supervisor(s) on the job  
4. Ongoing access to a dedicated trainer paid by your employer |