Operational Avalanche Risk Management

THIS ARTICLE IS THE SECOND IN A SERIES EXPLORING TECHNICAL ASPECTS OF SNOW AVALANCHE RISK MANAGEMENT.

PREAMBLE
In its first year of publication, The CAA’s Technical Aspects of Snow Avalanche Risk Management - Resources and Guidelines for Avalanche Practitioners in Canada (TASARM) is beginning to gain acceptance, with both new and existing risk management concepts and terminology being incorporated into several operations. The following article is intended to help provide linkages from current practice to operational risk management as described in TASARM. The CAA ITP is also beginning to incorporate TASARM, with the goal of having it as an established reference document for all professional avalanche practice in Canada.

1 INTRODUCTION
Avalanche operations refers to activities that include avalanche forecasting tasks and the direction and implementation of short-term mitigation measures in order to achieve specific organizational objectives. This article draws on material from TASARM and the upcoming A Land Managers Guide to Law, Ethics and Human Resources for Addressing Snow Avalanche Risk in Canada to outline the operational avalanche risk management process from hazard or risk identification through to mitigation. In this article, operational avalanche risk management is described in terms of how it applies to a typical day of work for an avalanche practitioner (e.g., technician, forecaster or guide). This typically involves two distinct risk assessments:

1 Office-based avalanche risk assessment and forecast in the morning prior to the upcoming day of outside work, which usually relies on avalanche, snowpack and weather data from a variety of sources.

2 Real-time avalanche risk assessment often in the immediate proximity of the avalanche hazard. This is generally an assessment of current risk, with “now forecasting”, and relies on the results of the morning risk assessment as well as any data collected from the field, up until the time of the assessment.

2 BACKGROUND
This section reviews background concepts found in TASARM and the Land Managers Guide that assist in understanding the underlying foundation for operational avalanche risk management.

2.1 Risk Tolerance and Acceptance
In order to effectively manage avalanche risk, it is important to understand societal risk tolerance and how that relates to the acceptable risk of an operation, and an individual.

2.1.1 Risk Tolerance
Risk tolerance is an organization’s or society’s readiness to accept the uncertainty and potential outcomes after the mitigation in order to achieve objectives (after CSA, 2011; ISO, 2009). Risk tolerance is a condition in that it represents expectations. Factors affecting Canadian tolerance to snow avalanche risks include:

- History of similar events: has it happened before and been deemed preventable?
- Multiple fatalities: as shown in an F-N plot of societal risk tolerances (Section 2.1.1.1, Fig. 1).
- Vulnerable victims (e.g., society is less tolerant of avalanche risk if minors are involved).
- Perceived ineptitude: where the public perceives the event was caused by ineptness, whether this is true or not.
- Role of government: where the government is seen as being responsible for public safety and when the public is not safe the government is asked to react (e.g., cost recovery for Search and Rescue groups or government funding for public avalanche safety programs).

Cam Campbell, Steve Conger, Brian Gould, Bruce Jamieson, Grant Statham
Canadian Avalanche Association, Revelstoke, BC
• Voluntary or involuntary risk (e.g., societal avalanche risk tolerance for workers (involuntary) is much lower than recreationists (voluntary)).

2.1.1.1 F-N Plot
Societal risk tolerance can be represented as a two-dimensional relationship between frequency and cumulative severity of outcome, called an F-N plot (Kendall et al., 1977) (Fig. 1). F-N plots typically define societal tolerance of risk in terms of the annual frequency (F) of events with number (N) or more fatalities. Based on the premise that society tends to be more concerned about multiple fatalities in a single event, as the number of fatalities per event as well as frequency increases, societal tolerance for the risk decreases.

On the F-N plot, societal risk tolerance can be divided into three zones:
• Intolerable.
• Tolerable if as low as reasonably practical (ALARP) (Section 2.1.1.2).
• Broadly tolerable.
The borders between these zones are typically plotted as a straight line on a logarithmic graph (Fig. 2).

2.1.1.2 ALARP
When risk tolerance is not provided by regulations, standards or the organization conducting the risk planning, it is often appropriate to develop a risk evaluation system that measures and ranks each risk scenario to help prioritize them. One strategy is to use the as low as reasonably practical (ALARP) criteria as outlined in Fig. 2. Under ALARP, high risks for potential harm must be reduced to a sliding scale where costs and benefits can be directly compared (CSA, 1997; Weir, 2002). Risks are as low as reasonably practical when the mitigation efforts result in a tolerable level of risk that cannot be reduced further without resources and costs being disproportionate to benefit gained, or where the solution is impractical to implement. This includes costs of not meeting the operational objectives (e.g., good skiing or keeping the road open).

FIG. 1: THE AVALANCHE RISK MANAGEMENT PROCESS. THE CENTRE OF THE DIAGRAM ILLUSTRATES THE PARALLEL PATHS THAT FOCUS ON EITHER PLANNING OR OPERATIONAL ACTIVITIES AND IDENTIFIES HOW THIS STRUCTURE ALIGNS UNDER THE ISO 31000 UMBRELLA.

FIG. 2: EXAMPLE OF “AS LOW AS REASONABLY PRACTICAL” (ALARP) RISK EVALUATION STRATEGY. AS SHOWN IN THE FIGURE, RISK IS MITIGATED TO A LEVEL AS LOW AS REASONABLY PRACTICAL WHEN THE RESIDUAL RISK IS ACCEPTABLE AND ANY ADDITIONAL RISK REDUCTION COMES AT A DISPROPORTIONATE MITIGATION COST OR EFFORT, OR IS IMPRactical TO IMPLEMENT.
2.1.2 Acceptable Risk

Risk acceptance is the informed decision to take a particular risk (ISO, 2009). Risk acceptance is an action in that it represents a decision, which for operations is often in the form of an operational risk band (Section 6). The operational risk band is described as the area between an upper and lower limit of acceptable risk. Decisions that, in hindsight, are above the upper limit (e.g., allowing too much uncertainty or exposure to harm) can lead to incidents that are intolerable. Decisions below the lower limit represent excessive conservatism and likely missed opportunity or unnecessary failure of meeting objectives. Excessive costs (e.g., death or economic loss) characterize errors of decisions outside either limit (McClung and Schaerer, 2006).

In general terms, hazard can be defined as the potential for harm or loss and risk is the exposure of something of value to the hazard. In operations hazard is expressed in terms of likelihood of triggering and destructive size, while risk is often expressed in terms of probability and consequence, or hazard and the exposure and vulnerability of the element at risk (Section 6.2).

In this process, the risk assessment is treated separately from hazard assessment. This is because avalanche risk management can conclude with a hazard assessment, which is often the case when producing avalanche hazard bulletins, or in the event that there is no hazard, there’s no need to carry on with a risk assessment. However, a risk assessment is typically based on an initial hazard assessment, and the exposure and vulnerability of the element at risk is then factored in.

Although this article focuses primarily on the risk assessment and mitigation steps of operational avalanche risk management, it is important to remember that successful operational avalanche risk management is based on sound planning and includes mechanisms for ongoing monitoring and review as well as communication and consultation.
2.2.1 Monitoring and Review
In an operational setting, ongoing monitoring and review of avalanche risk, forecasting and mitigation effectiveness is used to revise the risk assessment, avalanche forecast and mitigation strategies in a real-time continuous feedback loop. Furthermore, daily review of the risk assessment, avalanche forecast and mitigation (e.g. during an evening guide meeting) helps inform the baseline risk assessment for the following day by summarizing the current hazard and confidence levels, and identifying knowledge gaps.

2.2.2 Communication and Consultation
Ongoing internal communication and consultation throughout the risk management process helps to support and encourage accountability and ownership of risk within an organization (CSA, 2010). This includes an open and transparent risk management system that contains processes to consolidate information from a variety of sources. This could also include mechanisms that encourage team decision-making, as well as reporting of “near-misses”, which can be valuable to validate the effectiveness of a risk management program.

3 ESTABLISHING THE CONTEXT
3.1 Scope
The scope of operational avalanche risk management identifies objectives, hazard/risk criteria, relevant factors (internal and external) of the activities, or parts of the organization where the risk management process is applied. Defining the scope of the assessment (and resulting mitigation, if required) includes the clear statement of the operational objectives. The recognition of factors (internal and external) relevant to the organization or activities is also necessary to define the scope. Examples of scope of risk assessment for avalanche operations include:

- Complete a morning hazard evaluation for a helicopter-skiing operation and assess daily risk with the guiding team on a run-by-run basis.
- Conduct explosives control on a slope adjacent to a ski run in order to test instability and determine whether to open the area.
- Analyze regional snowpack data in order to determine if threshold snowpack depths have been reached for a remote site.
- The completion of a site-specific snowpack test to build upon an earlier desktop analysis in order to determine whether to ski a slope.

3.2 Situation
A situation is described by the intersection of three factors: element(s) at risk, scale and avalanche risk scenario(s). An element at risk describes the population, properties, environmental elements, economic activities and services in the area affected by the avalanche(s) (after IUGS, 1997). Scale refers to the physical extent of terrain or geographic area (i.e. spatial scale) of the hazard, as well as the time span (i.e. temporal scale) over which the element at risk is exposed. Scenarios are a hypothetical sequence of events that answer the question “What could go wrong (or right) during the exposure of the element(s) at risk to the hazard?”

Outlining the situation for an operational avalanche risk assessment begins with identifying the element(s) at risk and determining the physical (spatial) extent of terrain or geographic area where operations will occur. This may be specifically described in a risk-control plan or may be recognized and acknowledged as part of daily practice procedures. The temporal scale and associated risk scenarios are then formulated based on the scope.

4 TERRAIN IDENTIFICATION
Operational avalanche terrain identification is an ongoing recognition of the extent of the geographic area where avalanche hazard may exist. It typically occurs at various times and locations during an operational period, and is often part of a continuous search for terrain-correlated patterns of instability (Section 5.1). It may include a visual review of terrain atlas or mapping during the pre-field trip meeting. It also occurs in the field through the direct recognition of terrain configuration, steepness and other characteristics associated with avalanche initiation, flow and runout areas.

The terrain identification can be summarized in these sequential questions as the operational day progresses:
- Where can an avalanche occur?
- Can this terrain produce an avalanche?
- What is the severity of the terrain? (E.g. what is the scale of potential exposure; are there terrain traps?)
- What is my position relative to the boundaries or parts of the path?

Operational terrain identification for the current day is applied to base maps or photos prepared at the planning stage to visualize topography, as well as review of reports from other avalanche operations to determine specific terrain characteristics of particular avalanche problems. Subsequent aerial reconnaissance and/or ground-based observations may occur in conjunction with ongoing operational hazard/risk assessment as a component of both hazard and risk identification.

5 HAZARD ASSESSMENT
An operational avalanche hazard assessment is a series of activities undertaken to:
1. Describe the avalanche problem.
2. Recognize the potential for a harmful avalanche.
3. Monitor and analyze the environmental conditions that contribute to the hazard.
4. Estimate the likelihood and magnitude of a harmful avalanche. These activities fall within the general steps of identification, analysis and evaluation.

5.1 Hazard Identification
The first step of hazard identification is accomplished in the terrain identification. The next step applies the snowpack to the terrain. Here the first question is about thresholds, i.e. has the snow cover reached the threshold where ground roughness has been smoothed? This is followed by questioning whether threshold amounts of snow to produce a slab or instability have been reached or might be reached during the current weather conditions. This information relates to the consequence component of the hazard, i.e., what is the destructive size?

Hazard can also be identified through information regarding its likelihood, e.g. reports of Class I data from neighbouring operations, observed instabilities through testing or natural activity, or local avalanche problems described in prior operational meetings.

5.2 Hazard Analysis
Avalanche hazard analysis involves the systematic observation, monitoring and investigation of avalanche activity, and snowpack and weather conditions. In addition to emphasizing relevant measurement values, analysis considers the strength, weight and associated uncertainties of the gathered evidence. The careful observation and systematic recording of these factors supports the feedback loop for operational avalanche hazard analysis.

5.2.1 Avalanche Activity
Observation of avalanche activity is direct evidence of snow cover instability and considered the strongest supporting information when undertaking the hazard analysis. An important analysis tool is discovery through patterns of avalanche activity. The compilation of this information (or the identification of a lack of it) from both local and nearby operations is a vital step in the pre-field trip operational meeting and should be included in structured hazard and risk assessments (e.g. AM Hazard & Risk Assessment Worksheet).

5.2.2 Snowpack
Hazardous avalanches typically require a threshold snow depth of 30 to 60cm beyond the amount required to smooth ground roughness or irregularities. Upon nearing this threshold, regular observation and recording of snowpack structure and instability is necessary. Since it is not feasible to assess every slope, extrapolation of this information across the spatial scale of the situation is essential. Temporal change of this information necessitates monitoring on an appropriate interval to minimize uncertainty. Understanding the distribution of snow structure and characteristics of weak layers across the terrain is an ongoing requirement in avalanche operations.

5.2.3 Weather
Weather factors have a direct influence on the snowpack, which in turn directly influence the avalanche hazard. Typical observations include sky cover and solar radiation, precipitation type and intensity, air temperature ranges, relative humidity, recent snowfall and total snowpack depth, wind direction and speed, and blowing snow (CAA, 2016a). Spatial redundancy of observations helps to reduce uncertainty.

5.3 Hazard Evaluation
Operational hazard evaluation consists of comparing the results of the analysis against benchmarks such as an ordinal set of descriptors. The Canadian Avalanche Association’s hazard rating scale used for InfoEx hazard assessments (Table 1) is an example of operational hazard evaluation. Its primary objective is to accompany an InfoEx hazard assessment.

<table>
<thead>
<tr>
<th>Hazard level</th>
<th>Likelihood of triggering</th>
<th>Size and distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 (Black)</td>
<td>Natural and artificially triggered avalanches almost certain.</td>
<td>&gt; Size 3 avalanches are widespread.</td>
</tr>
<tr>
<td>4 (Red)</td>
<td>Natural avalanches likely; artificially triggered avalanches very likely.</td>
<td>Size 2-3 avalanches are widespread; or &gt; size 3 avalanches in specific areas.</td>
</tr>
<tr>
<td>3 (Orange)</td>
<td>Natural avalanches possible; artificially triggered avalanches likely.</td>
<td>&lt; Size 2 avalanches are widespread; or size 2-3 avalanches in specific areas; or &gt; size 3 avalanches in isolated areas.</td>
</tr>
<tr>
<td>2 (Yellow)</td>
<td>Natural avalanches unlikely; artificially triggered avalanches possible.</td>
<td>&lt; Size 2 avalanches in specific areas; or size 2-3 avalanches in isolated areas.</td>
</tr>
<tr>
<td>1 (Green)</td>
<td>Natural and artificially triggered avalanches unlikely.</td>
<td>&lt; Size 2 avalanches in isolated areas or extreme terrain.</td>
</tr>
</tbody>
</table>
and provide a relative measure of avalanche hazard that corresponds to a set of definitions for each of the five levels. Operational hazard evaluation is an ongoing process that occurs in real-time and typically leads to forecasts within time scales of 12 to 72 hours.

5.3.1 Avalanche Problem
Operational hazard evaluation integrates weather, snowpack and avalanche analysis with local terrain factors and weather forecasts. The avalanche hazard evaluation determines the character (Atkins, 2004), elevation and aspect, likelihood, and size of potential avalanche events based on the analysis. This construct of the avalanche problem describes the avalanche hazard and regularly includes the degree of confidence and representation of uncertainties associated with the estimation.

5.3.2 Conceptual Model of Avalanche Hazard
The conceptual model of avalanche hazard (Statham et al., in prep) is a series of independent concepts and components that when linked together in a stepwise fashion, provide an organizing framework for the process of avalanche hazard assessment (Fig. 4). Starting from an initial state (operational objectives, scale) the model proceeds through a succession of analytical steps (avalanche character, location, likelihood of triggering, avalanche size) before concluding with a rating of avalanche hazard.

Avalanche character (Atkins, 2004) describes different types of avalanche regimes, each of which presents a general, repeatable pattern of potential or observed avalanche activity that suggests a distinct approach to risk treatment (Statham et al., in prep). An avalanche character (e.g. wind slab, storm slab, persistent slab, deep persistent slab, wet slab, loose wet, loose dry, cornice fall and glide avalanche) is attributed to specific locations by aspect, elevation, vegetation bands, operating zones or terrain features. Likelihood of triggering is a function of the spatial density and distribution of the instability and the sensitivity to triggers of various sizes by natural or artificial means. Destructive size is typically represented by the avalanche size classification system (CAA, 2016a). The uncertainty in likelihood and magnitude (based on the uncertainty in the inputs) should be described/displayed and communicated.

6 RISK ASSESSMENT
A risk assessment provides evidence-based information and analyses to support informed decisions on how to treat particular risks and how to select between mitigation options (after ISO, 2009). An operational avalanche risk assessment is grounded in standardized methods along with the expertise and competence of the individuals performing the assessment. It is a continuous and iterative process that occurs on an ongoing basis, and may or may not be recorded in a variety of formats (e.g. notebooks, forms and/or databases). An operational avalanche risk assessment builds on the hazard assessment results with these additional efforts:
1. Find, recognize and describe the element at risk.
2. Analyze its exposure and vulnerability to the hazard.
3. Determine the level of risk.
4. Compare the results to a given criteria to determine whether the risk meets the identified risk tolerance.

FIG. 4: THE CONCEPTUAL MODEL OF AVALANCHE HAZARD (STATHAM ET AL., IN PREP) IS USED TO CONSTRUCT THE AVALANCHE PROBLEM. FOR EACH AVALANCHE CHARACTER AT A SPECIFIC LOCATION, AVALANCHE HAZARD IS DETERMINED THROUGH EVALUATING THE RELATIONSHIP BETWEEN LIKELIHOOD OF TRIGGERING (A FUNCTION OF THE SENSITIVITY TO TRIGGERS AND SPATIAL DISTRIBUTION OF A WEAKNESS) AND THE EXPECTED AVALANCHE SIZE. AVALANCHE HAZARD IS OFTEN REPRESENTED AS A RANGE OF VALUES FOR BOTH LIKELIHOOD OF TRIGGERING AND DESTRUCTIVE SIZE, REPRESENTING VARIABILITY AND UNCERTAINTY.
These activities fall in the general steps of identification, analysis and evaluation. An example of a commonly used operational avalanche risk assessment method is the CAA’s morning (AM) and afternoon (PM) Hazard and Risk Worksheets.

6.1 Risk Identification Through Scenarios
The risk identification step connects the hazard assessment to the element at risk through use of risk scenarios. The hazard assessment result provides a location, an estimation of the likelihood of occurrence, and magnitude for the potential avalanche hazard. This potential event is then combined with an element at risk.

In an operational setting, scenarios are typically mental visualizations of the planned activities and objectives that may occur in the area subject to the hazard. This step involves answering the question “Given the avalanche forecast and the locally observed conditions, what can happen?” This question serves both as an identifier of scenarios and supports the constant consideration aspect of maintaining situational awareness.

Visualizing scenarios allows consideration of various outcomes based on changes to the hazard or application of mitigation measures. Envisioning multiple scenarios assists the subjective judgment of event likelihood, consequences and level of uncertainty.

6.1.1 Element at Risk
The element at risk is determined by the operational setting and objectives. Within this parameter, elements at risk can be identified through answering the question “What or who is vulnerable to a potential avalanche?”

In operational risk assessment, the element at risk is typically people, but may include other elements as determined by the operational setting and specific objectives. For example, an avalanche risk manager for a highway might consider people as the primary element at risk, and vehicles and commerce as secondary.

6.1.2 Exposure
Each scenario typically involves different exposure levels of the element at risk to the avalanche hazard. Exposure is the extent to which the element(s) at risk is (are) subject to potential avalanche hazards. It is a function of the time period and position the element is present within an avalanche path. Controlling or managing exposure has a vital effect on the uncertainties associated with potential avalanche hazard.

6.1.3 Vulnerability
Each element at risk has an associated vulnerability, which is defined by the fraction of loss given that the element at risk is hit by or caught in an avalanche with specified magnitude.

When people are affected by avalanches, vulnerability is the probability of death (after IUGS, 1997). Vulnerability of people is a function of:

- The personal protective equipment they are wearing or carrying (e.g. transceiver, airbag and helmet).
- Whether the person is in and protected by a building or vehicle, or whether they are outside and fully exposed to the avalanche.
- The ability of the person to free themselves from an avalanche if caught, which depends on, for example, their strength, ability and mode of travel (e.g. in a vehicle or on skis, snowmobile or foot).
- The ability of the person to be rescued in a timely manner if buried, which depends on, for example, the proximity, number and ability of rescuers, as well as the rescue equipment available to them.

6.2 Risk Analysis
Risk analysis is a series of actions undertaken to comprehend the uncertainties associated with the visualized scenarios. Operational avalanche risk analysis typically follows different approaches depending on whether the risk analysis is taking place in the office on the morning of a field day, or in the field in real-time. A risk analysis approach for the first situation is presented by Statham and Gould (2016), where the exposure and vulnerability of the element at risk is systematically combined with the avalanche hazard to determine risk. This approach breaks risk into the components onto which mitigation can be applied (i.e. direct mitigation acts on the hazard, whereas indirect mitigation acts on the exposure and/or vulnerability of the element at risk), and, therefore helps to streamline the choice between mitigation options (Section 8).

However, in real-time in-situ situations, a more intuitive risk analysis model that helps to maintain situational awareness through repetitive consideration is typically used. This model is based on Kaplan and Garrick’s (1981) probability and consequence risk definition, where probability is a function of the likelihood of an avalanche occurring and the exposure of the element at risk, and consequence is a function of the expected avalanche size and the vulnerability of the element(s) at risk. Answering the following questions guides the analysis:

1. How likely is it that a specific scenario will happen?
2. If it does happen, what would be the consequences?
3. What uncertainties can be reduced?

6.3 Risk Evaluation
Avalanche risk evaluation compares the results of risk analysis with risk criteria to determine whether the risk is acceptable. The amount of uncertainty associated with the likelihood of the hazardous event or the potential consequence is also
considered in risk evaluation. In an operational setting, risk evaluation is often conducted in tandem with risk analysis where both are part of the same step in the risk assessment process. Typical strategies for operational risk evaluation use the operational risk band concept outlined in Section 2.1.2 as the evaluation criteria.

At a fundamental level, risk evaluation works through the questions:
1. What is tolerable? (Section 2.1.1)
2. How safe is safe enough? That is, what is acceptable? (Section 2.1.2)
3. What needs to be done?

What is tolerable is a prerequisite drawn from establishing the context. What is acceptable is the basis for the decisions of:
- Whether an activity should be commenced.
- Whether a risk requires mitigation.
- Mitigation prioritization.
- Which of a number of options should be chosen.

Implicit in the question of “how safe is safe enough” is the critical continuous feedback that occurs in operational avalanche risk assessment. This feedback comes in the evaluation of whether the chosen method of mitigation is effective and has altered the risk level to within what is acceptable. For example, the continued analysis and re-evaluation of hazard following explosive avalanche triggering efforts to determine if the avalanche forecast has changed substantially from the previous one. This reflects a return trip through the assessment steps prior to deciding to remove the mitigation measure of temporary closure and evacuation.

7 UNCERTAINTY AND DECISION AIDS
Uncertainty and confidence in the assessment are inversely related, where the lower the uncertainty, the greater the degree of confidence in the estimate of risk (Willow & Connell, 2003). One way to reduce epistemic, or knowledge-source uncertainty, is to use independent methods in the same assessment (e.g. decision aids). Fig. 5a shows the risk spectrum from low to high, with the operational risk band (ORB) somewhere in the middle. In this case the risk assessed with an aid is in fairly good agreement, with the risk assessed by an expert using judgement, so the assessment aid reduces uncertainty and increases confidence.

In Fig. 5b the decision aid indicated that the risk level is well above the ORB, but expert judgement suggests it is well within it. Again, assessment aids are often conservative and we need expert judgement to determine the true risk levels; however, this situation should raise some red flags. It may lead us to apply additional mitigation, just to be on the safe side. Or we may seek more targeted information to reduce uncertainty, and reassess to make sure we didn’t miss anything. In these sorts of situations, we can often look at the underlying components of the assessment aid and find specific parameters that were perhaps weighted higher than what our judgement suggests, and we can adjust our assessment accordingly. Or upon further consideration, we may recognize that the assumptions or dataset limitations behind the decision aid limit its applicability to the risk being considered.

7.1 Precautionary Evacuation and Restricted Access
The simplest short-term measure is precautionary evacuation and restricted access, as the risk is effectively eliminated while the measure is applied. Since precautionary evacuation and restricted access is a form of exposure control, the measure can be effective for people and any object that is mobile (e.g. a person on foot or in a vehicle), but cannot protect fixed property or infrastructure. Examples are provided in CAA (2016b), and they include:
- Evacuation of buildings.
- Curfew, if buildings are designed to withstand the effects of an extreme avalanche.
- Temporary closure, traffic delays or seasonal closures in the case of transportation corridors.
• Daily or temporary ski run or zone closures in the case of ski areas, and mechanized ski operations.
• Restricted access for personnel with limited training and experience (e.g., only those with CAA Level 2, and/or professional CAA membership allowed to access complex terrain during high hazard). This would normally be outlined in specific procedures and policies in an operation’s avalanche risk management plan (Section 8.3).

8.2 Route Selection and Group Management
Route selection (or route finding) and group management is a form of exposure control used in all backcountry travel (i.e., for recreational, commercial and industrial purposes). It involves actively managing the movement of people through areas of avalanche hazard. Deliberate adjustments to the exposure of individuals or groups is routinely practiced in the daily operations of avalanche professionals travelling in the backcountry. Similarly, in a transportation setting, convoys are occasionally used to manage the exposure of traffic.

In real-time, the slope-scale risk mitigation practiced by avalanche professionals relies on an intimate understanding of the nature of avalanche formation, and the nuanced interaction between snowpack, terrain and people. Its critical function is the ability to make micro-adjustments to people’s position and time spent in avalanche terrain that reduces their risk by limiting their exposure to the hazard. At its core level, it can be processed as probability and consequence; however, the tools to mitigate the risk generally involve adjusting the hazard, the exposure, or the vulnerability (Section 6.2).

8.3 Policy and Procedure
Risk control based on procedure and policy (P&P) involves the use of a structured operating procedure (e.g., risk matrix) to restrict or enable access to hazard areas based on forecasted hazard levels, terrain classification and level of training of the user. These systems are normally employed in an environment where there may be an array of field-based activities occurring at a large scale, and there is potentially a spectrum of staff training levels. They may also be used by a guiding or field team to restrict or enable specific routes (e.g., a run list). Details regarding the procedures and policies would normally be described in an avalanche safety plan.

Terrain classification used within the scope of P&P-based risk control is often determined in advance during the planning stage. Hazard ratings may be provided by a forecasting program within the organization, outside contract services, or from publicly available sources. However, it is important to note that P&P-based risk control should be guided by hazard assessments specific to the element at risk. If non-specific or inappropriate sources are used, it must be understood that there are often more restrictions than with risk control based on hazard and guidance provided by a forecasting program within the organization (or from contract services), due to potential differences in spatial and temporal scale, intended audience and element-at-risk characteristics.

The risk control procedure (risk reduction parameters and access decisions) are typically provided in a table or matrix format, an example of which can be found in Campbell et al., (2016).
Avalanche safety equipment and training are standard requirements for all exposure to avalanche terrain, whether in a recreational or professional setting. These requirements, as well as an emergency response plan, are all normal components of P&P-based risk control. For workplaces, these are normally outlined in the organization’s avalanche safety plan (ASP), along with maps and other procedures and policies (e.g., risk matrices).

8.4 Artificial Triggering and Snowpack Compaction

Artificial triggering reduces the hazard by releasing unstable snow at controlled times (during evacuations) and/or reduces the subsequent likelihood of triggering large avalanches. Triggering measures range from ski cutting and hand charging with explosives to sophisticated remote avalanche control systems utilizing either explosives or gas. The level and sophistication of triggering technique or system is normally based on cost-benefit evaluation and worker safety considerations. Often a combination of systems will be employed for a particular control program (e.g., ski area control routes that use ski cutting and hand charging).

The intent of snowpack compaction is to disrupt layers in the snowpack in order to reduce future instability. The snowpack can be compacted using intentional boot or ski packing, or as a corollary of public recreational ski or snowmobile traffic. The impact of compaction on hazard reduction, and resulting success as avalanche risk mitigation measure, depends on the snow and weather conditions that develop subsequent to compaction (generally over weeks to months).

9 REFERENCES


