AN OPERATIONAL SPECIFIC AVALANCHE RISK MATRIX (OSARM): COMBINING THE CONCEPTUAL MODEL OF AVALANCHE HAZARD WITH RISK ANALYSIS AND OPERATIONAL MITIGATION STRATEGIES

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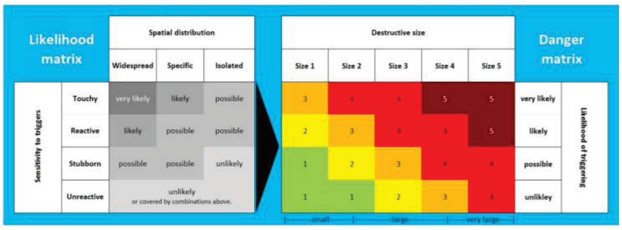
ABSTRACT: Object specific avalanche forecasting is common in many countries and typically assesses avalanche hazard on an mountain (> 10 km^2) scale or single path (<1km^2) scale, whereas public avalanche forecast services (>100 km^2, drainage/mountain range scale) typically apply the North American or the European Avalanche Danger Scale to communicate the avalanche hazard. These scales are of limited usefulness in object specific avalanche forecasting as both the exposure and the vulnerability of the element at risk must be considered. The Operational Specific Avalanche Risk Matrix (OSARM) is a concept that seeks to improve the integration of the risk analysis in the planning phase, with the decision making and applied mitigation measures in the operational phase. In the planning phase a qualitative risk assessment is conducted to determine to which avalanche size(s) the element at risk was exposed to and how vulnerable it is to each avalanche size. In the next step the accepted risk and possible mitigation strategies are defined together with the client. Based on this analysis, two or three risk ratings with associated mitigation strategies are defined. The OSARM has been operationally implemented in Norway during the winter season 2017/18 for two projects related to avalanche forecasting for worksites and for another project that is related to avalanche forecasting and avalanche control for a transportation corridor.

KEYWORDS: Avalanche forecasting, local forecasting, operational forecasting, danger scales, danger levels, Conceptual model of avalanche hazard, OSARM, avalanche risk, risk mitigation, ISO 31 000, TASARM.

1. INTRODUCTION

Avalanche forecasting operations have large variations in operational objectives and in temporal and spatial scales. Typically, public avalanche forecast services produce forecasts for large areas (Drainage or Region scale) with the objective of providing information about the avalanche hazard that enables the public to make safer choices during backcountry recreation or for professional avalanches services. On the other hand, operational avalanche forecasts for worksites, transportation corridors, occupied structures and similar, will often have a much smaller spatial scale (> 10 km² for multiple paths or < 1 km² for single paths) with the operational objectives of keeping workers safe while simultaneously minimizing the frequency and duration of closures.

The North American Avalanche Danger Scale (ADS) and the European Avalanche Danger Scale are commonly used all over the world. These scales are only valid for areas of at least 100 km^2 and do not consider the Element at Risk, and is therefore not applicable for object specific avalanche forecast operations (Kristensen, 2013).



Likelihood matrix		Spatial distribution		
		Widespread	Specific	Isolated
Sensitivity to triggers	Touchy	very likely	likely	possible
	Reactive	likely	possible	possible
	Stubborn	possible	possible	unlikely
	Unreactive	unlikely or covered by combinations above.		

Destructive size					Danger matrix	
Size 1	Size 2	Size 3	Size 4	Size 5		
3	4	4	5	5	very likely	Likelihood of triggering
2	3	4	4	5	likely	
1	2	3	4	4	possible	
1	1	2	3	4	unlikley	

Figure 1: Avalanche Danger Assessment Matrix (Müller et. Al, 2016a)

The Conceptual Model of Avalanche Hazard (CMAH) provides a systematic process for assessing avalanche hazard – it also does not consider the element at risk (CAA, 2016). The hazard is displayed in the hazard chart combining the likelihood of avalanches and expected avalanche size. CMAH concept is not linked to any specific danger level scale (Statham et. Al., 2017).

The Avalanche Danger Assessment Matrix (ADAM) (Figure 1) combines the CMAH with a tool for deciding the avalanche danger rating according to the European avalanche danger scale (Müller et. Al, 2016a). ADAM only considers the avalanche hazard and is only applicable for large spatial scale forecasting operations (minimum 100km^2).

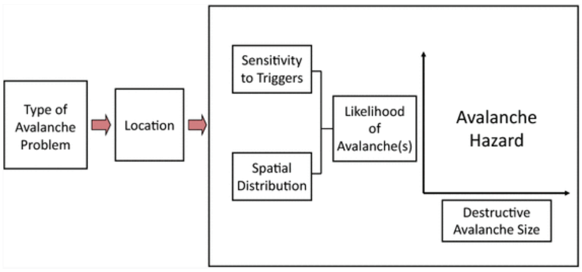


Figure 2: The conceptual model for avalanche hazard (Statham et. al 2017)

For object specific avalanche forecasting the ER must be considered in the decision-making process on when to apply mitigation strategies. However, the avalanche hazard is independent of the ER and needs to be assessed separately in the day-to-day avalanche forecasting process (Statham, 2008. Kristensen, 2013. CAA, 2016. Statham, 2016. Statham et. Al, 2017).

The concept of an Operational Specific Avalanche Risk Matrix (OSARM) (Figure 4) combines these elements. It is built upon the foundation of standard risk management processes described in the Technical Aspects of Avalanche Risk Management (CAA, 2016) and the hazard chart from the CMAH. The key components of the concept are:

- The possible mitigation strategies defined in the planning phase of the project decide the amount of (danger/risk/mitigation) levels in the matrix.
- The thresholds for the different (danger/risk/mitigation) levels are defined in close cooperation with the risk owner to ensure a common understanding of these thresholds.
- The OSARM concept can be applied independently of the method of defining likelihood/probability of avalanche(s) and method for risk assessment.

This paper does not indicate that specific methods for assessing avalanche hazard or risk assessments are better or more correct than others. We will describe three examples on how this concept was applied in Norway for object specific avalanche forecasting operations during the winter of 2017-2018 and discuss some of the benefits and challenges we encountered during the process.

All definitions used in this paper can be found in the Technical Aspects of Snow Avalanche Risk Management, TASARM (CAA, 2016), and we encourage other avalanche professional to apply these definitions to make sure that we are all speaking the same language.

2. METHODS

Using the approach described in CAA, 2016 the work flow is separated in a planning and operational phase. Initially the context needs to be established for each project individually (Figure 3). As a next step, the terrain within the operation area is identified and the hazards and risks are assessed.

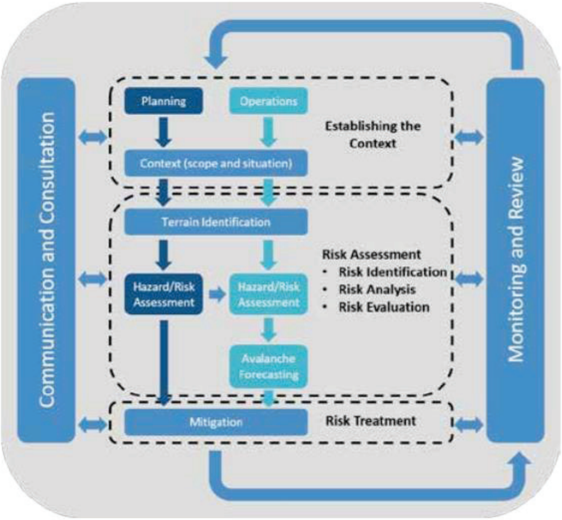


Figure 3: Avalanche risk management process according to ISO 31 000 (CAA, 2016).

2.1 Planning phase

The planning phase starts with establishing situational awareness and context from operational objectives and spatiotemporal scales (Statham et. Al, 2017). In the next step, the terrain characteristics and possible hazards are identified. This includes, amongst other factors, expected run-out distances for different avalanche sizes, local snow climate and weather patterns, snow loading patterns, typical avalanche problems and types, etc. This information is used as a base for the risk assessment. Already at this point, the client must be strongly involved in the process. It is crucial to make sure that all stakeholders have a common understanding of the accepted risk (AR) or operational risk band (ORB). Clear communication is essential as the challenge is often to meet quantitative, long term and company-wide risk management objectives on the Risk Owner side with (mainly) qualitative short-term avalanche forecasting and risk management.

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2.1.1 Risk treatment and mitigation

Risk can be mitigated by changing the hazard, i.e. frequency and/or magnitude, or changing the exposure and/or vulnerability of the element at risk (CAA, 2016).

In any given objective specific avalanche forecasting operation, several different mitigation measures can be applied individually or in combination. Examples are temporary closures, releasing avalanches preventively with explosives, travel restrictions, training and use of avalanche safety equipment, etc. (CAA, 2016)

One example is shown in figure 6, where one part of a construction site is exposed to size 2 avalanches while another part of the same construction site would only be exposed to size 3 and larger avalanches. Based on this analysis, two or three specific risk ratings with associated mitigation strategies were defined and then implemented into the hazard chart of the CMAH. (Figure 4) This needs to be approved by the risk owner before implemented operationally.

2.1.2. Defining the OSARM mitigation levels

Based on the possible risk mitigation strategies in a specific project, the amount of mitigation levels, their thresholds and their consequent measures are defined. It is important that the OSARM is not called an *avalanche danger scale* and that the risk levels are not described as *danger levels* to avoid confusion with public avalanche forecast services for larger areas.

2.2 Operational phase

During the operational phase of the project the forecasters should be able to focus only on the hazard assessment because of the work that was done in the planning phase. A given hazard (likelihood x avalanche size) will then trigger a predefined risk rating that is directly linked to operational procedures at the work site. Communication of the uncertainty related to the hazard assessment is very important. One way to do this is to visualize the current avalanche problems as rectangles in the OSARM as shown in figure 4. Then it needs to be defined in the planning process if the worst-case scenario (upper right corner) triggers the risk level or not.

2.2.1 Review, monitoring and quality control

As illustrated in Figure 3, a consequent review and monitoring process should be an integral part of daily operations and should be reviewed on a regular basis. When forecasting for construction sites especially, the ER might change during the project due to progress in the construction work. This might cause the need to review and change the risk levels in the OSARM during the winter.

3. RESULTS

The OSARM has been implemented in 3 operational settings in Norway during the winter season of 2017-18 and covered varying spatial scales with different elements at risk. Two of the projects are related to avalanche forecasting for worksites and the other project is related to avalanche forecasting and avalanche control for a transport corridor.

Project name	**Tyin – Årdal**	**Hwy 136 Romsdalen**	**Hwy 16 Øye**
Spatial Scale	Mountain (>10km^2)	Path (< 1km^2)	Slope (< 1km^2)
Number of paths	9	2	1
Element at risk (ER)	Cars and snow plowers	Workers and equipment	Workers

Table 1: Overview of the three projects where the OSARM concept was applied for the winter 2017 – 2018

3.1 Case 1: County Road 53 Tyin – Årdal

County road 53 between Tyin and Årdal is a high mountain public road in Norway with an average traffic of about 300 cars per day. The road is mainly located above treeline and is exposed to 9 avalanche paths (Farestveit, 2012). Avalanche release areas are located from 1000-1300 m.a.s.l. and have a vertical drop to the road ranging from 50m to 350m.

For the first season (2016-2017) only two risk levels were applied with the following definitions:

Green: No actions required

Red: Avalanche control recommended.

After evaluating the first season, a third level was introduced to the scale for the second and the OSARM was developed to improve the common understanding of these danger levels and their thresholds:

Green: *No actions required*

Yellow: *Avalanche control recommended, OR Avalanche control can be recommended on short term.*

Red: *Avalanche control recommended, and maintenance crew are advised not to work on the road*

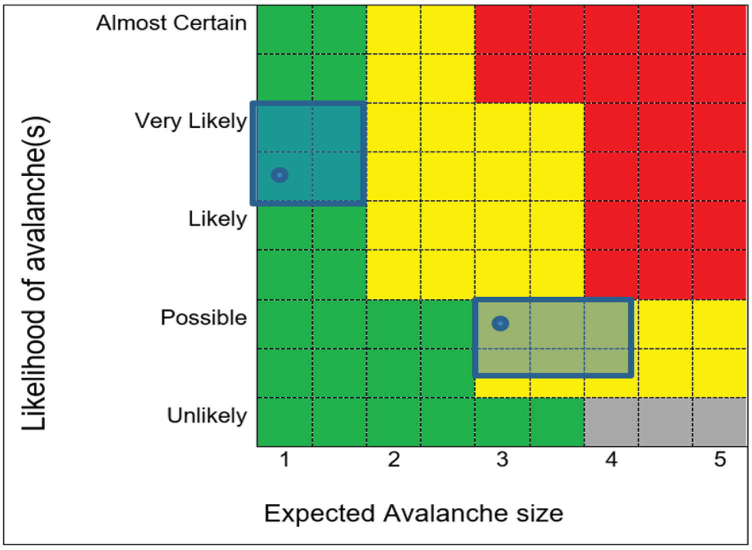

Figure 4: Operational Specific Avalanche Risk Matrix from the Tyin – Årdal project. This chart gives the opportunity to display the avalanche hazard combining the likelihood of triggering and expected avalanche size. In this example, persistent slab avalanche(s) are possible size 3-4 and Storm slabs are very likely size 1-2.

Figure 5: County Road 53 Tyin - Årdal after a size 3 avalanche was preventively released using RACS in March 2018. Photo: Wyssen Avalanche Control

3.*1.1 Operations 2017-2018*

We decided to implement the method of assessing likelihood of avalanche(s) as described in the CMAH, where the likelihood is a function of *sensitivity to triggers* and *spatial distribution* of the avalanche problem (Statham et. Al, 2017). During the winter season, no natural avalanches hit the open road. A total of 153 avalanches were observed. 94 of those were preventively released using RACS.

Figure 5 illustrates that when in the evaluation the likelihood of avalanches was rated high, the number of observed (naturally or preventively) released avalanches was also large. Consequent communication of forecasted hazard and proposed mitigation level to the client – supported by this data - resulted in a high level of trust. The amount of data is too limited to draw any conclusions, but it can to some extent be interpreted as a verification of the method. Even though all paths are close to the road and observations are made daily, some avalanches can occur at night and in bad visibility without being observed.

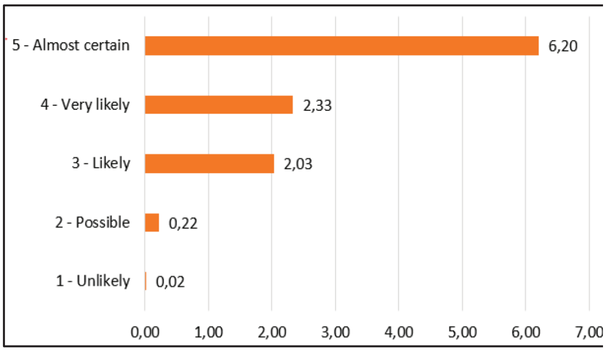

Figure 5: Number of observed avalanches (natural and explosive triggered) per likelihood classes (divided by the amount of forecasted days in each class) at Country Road 53 Tyin - Årdal 2017-2018. N avalanches = 164, N forecast days = 152

3.2 Case 2: Construction site Highway 136 Romsdalen

Highway 136 goes through the Romsdalen valley with the famous Troll-Wall. Several avalanche paths threaten the road therefore the Norwegian Public Road Administration (NPRA) decided to build a tunnel and a protection dam to mitigate the risk from two avalanche areas. To be able to keep the construction going through the winter, an avalanche forecasting operation was established to reduce the risk of avalanches affecting the workers to an acceptable level.

In the planning phase of the project, the NPRA (risk owner) suggested to only use the probability of an avalanche reaching the ER to define the three different hazard/risk levels. This approach has a big drawback because it does not consider the avalanche size, which again affects both the exposure and the vulnerability. To account for this an OSARM was developed for each of the two paths (Figure 7). The measures related to the different risk levels were:

- **Green:** *Presence permitted on entire site.*
- **Yellow**: *Presence in area A not permitted (Figure 6).*
- **Red:** *Presence in are A and B not permitted (Figure 6).*

3.2.1 Operations 2017-2018

Due to the small spatial scale of the project, the methodology to assess likelihood of avalanches described in Case 1 was not applied. This is discussed in more detail in chapter 4.2. A big challenge of this project was the lack of snowpack data. Both release areas are not accessible without putting the observer at great risk and there are no nearby slopes that would provide relevant information.

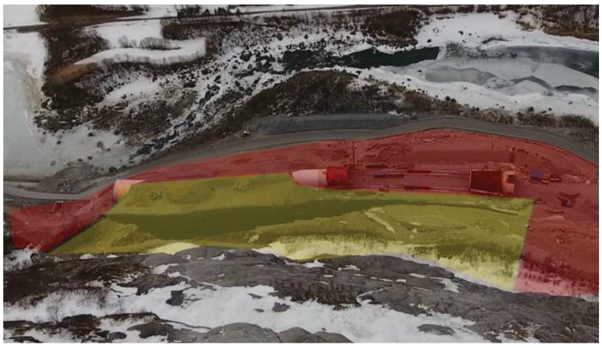

Figure 6: The construction site for a at Hwy 136. The different colors on the polygons represent areas that is closed due to avalanche hazard. A size 2 avalanche could reach area A (yellow) area but would not affect area B (red). Therefore, work was allowed in area B, independent of the likelihood if the expected size was 2 or smaller.

A big challenge during this project was the lack of snowpack data. Both release areas are not accessible without putting the observer at great risk and there are no nearby slopes that would provide relevant information. This, of course, resulted in a high degree of uncertainty in the forecasting many days during the winter. As a result, area A was closed for 57 days during the winter. Area B was closed for 4 days.

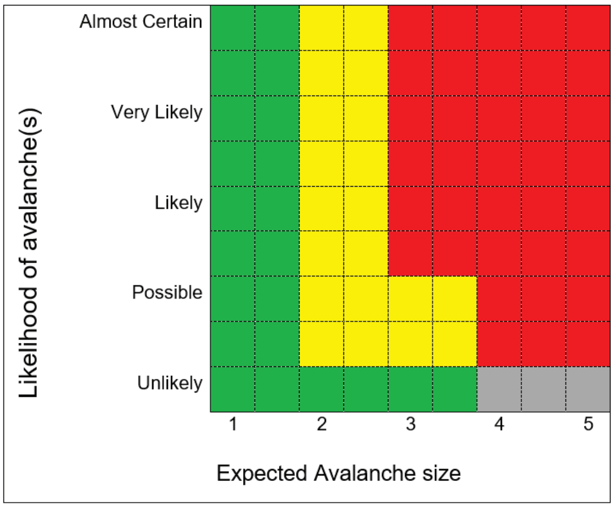

Figure 7: Example of the OSARM matrix for a worker at the Fantebrauta path (construction site at Highway 136 in Norway).

In the beginning of January all involved parties participated in an evaluation meeting to discuss the thresholds for the risk levels. The main question was if the combination of "*possible* and *size 2*" should be changed to green. NPRA together with the general contractor concluded that an increased risk acceptance was not tolerated, and the original thresholds were kept.

3.3 Case 3: Construction site Highway 16 – Øye Eidsbru

At the construction of a new section of highway 16, the general contractor suspected that the workers were working in an area that could be exposed to avalanche hazard. During the excavation of moraine masses to make room for a concrete tunnel, a slope with an incline of approximately 40° was artificially created. During the unusually strong winter of 2017/2018, workers started to worry about the increasing snow masses above them. At this location, even a size 1 avalanche could be fatal because of the nature of the construction site (metal bars, etc.). An avalanche forecasting operation was established to reduce the risk to an acceptable level by closing the exposed area during periods with elevated avalanche hazard. In addition, avalanche rescue equipment was purchased, workers were trained in the use of the equipment, and an avalanche rescue plan was developed.

As in Case 2, the methodology to assess likelihood of avalanches described in Case 1 was not applied. This is discussed in more detail in chapter 4.2.

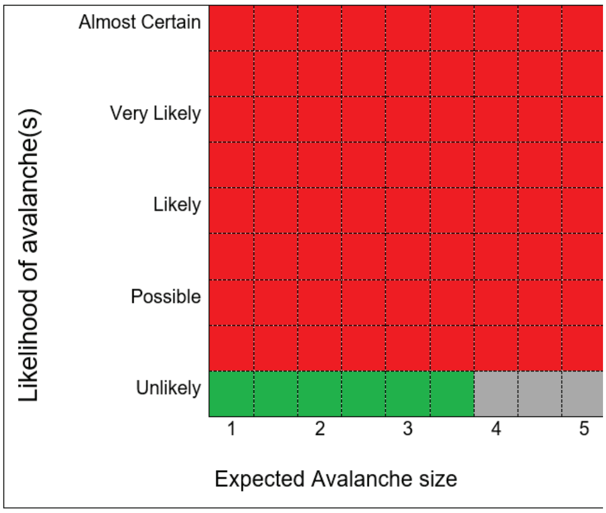

Figure 8: Example of the OSARM matrix for a worker the construction site at Highway 16 in Norway.

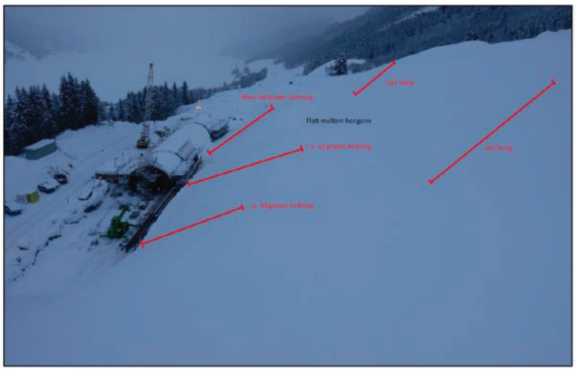

Figure 9: Construction site at Hwy 16 - Øye. Even a size 1 avalanche could potentially kill a person due to the nature of the construction site. This can be defined as a very severe terrain trap, increasing the vulnerability of persons working there.

4. DISCUSSION

Using the CMAH allowed the avalanche forecasters to work as objectively as possible with avalanche hazard. Extending this method to the OSARM framework and communicating predefined mitigation levels created a clear communication channel between the two parties. Yet, we encountered multiple challenges during the implementation and execution of OSARM:

4.1 Qualitative vs. quantitative approach

There is lot of literature on different methods to assess the probability for an avalanche to release on a specific slope (i.e. Kristensen 2013). However, these approaches require a lot of relevant data of weather and avalanche observations over a long period of time. In operational forecasting for specific objects this data is often not available, depending in the temporal scale of the project. A long-lasting highway operation might have it, but starting up new operations, forecasting for construction sites and other short-term projects, a different approach is needed.

4.2 Estimation of likelihood of avalanches applying the Conceptual Model of Avalanche Hazard

In the CMAH, likelihood of avalanches is defined as "*the chance of an avalanche releasing within a specific location and time period, regardless of size*" and considers two factors that contribute to the likelihood: *sensitivity to triggers* and *spatial distribution* (Statham et. al., 2017). Our experience from the Tyin project indicates good results applying this method to predict the avalanche activity (Figure 5).

Yet, the likelihood of avalanche(s), as defined here, is dependent of both temporal and spatial scale. For example, on a larger (region) scale, 10 avalanches expected in one day might be rated as likelihood class *avalanches unlikely*. On a slope/path scale the likelihood of one avalanche releasing for one day might be considered *almost certain* if one is very sure that an avalanche will release in this one path. In other words: on this scale the likelihood assessment is moving towards the skiers' approach.

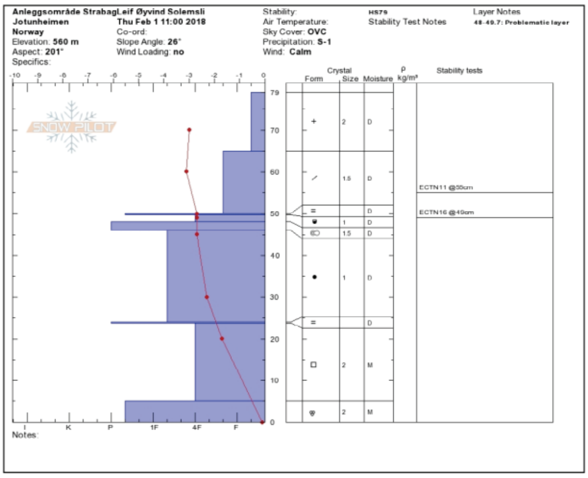

Figure 8: Snow profile from the Construction site at Hwy 16 - Øye. Several persistent week layers are present in the snowpack. 2mm moist facets 5-25cm above ground does not show any signs of instability in any tests. The crust at 47-49 cm lacks a cohesive slab above. This assessment was strengthened by tests and multiple profiles in the same area. In this situation the likelihood for natural avalanche release was considered "*unlikely*".

4.3 Consistency for avalanche forecasters

An avalanche forecaster might forecast for several different projects for different clients and objects during the same period. If for example, a five-level danger scale is used in all projects, the forecaster always must keep in mind that in each project the definitions for each danger level might be different. A danger level 3 might not mean the same in terms of avalanche size and likelihood, which might be confusing on a busy day with a lot of pressure.

By applying the principle from CMAH to describe the avalanche hazard by estimating the likelihood of avalanche(s) and expected avalanche size, the hazard evaluation is very similar. Our team found this very useful during the last winter season when switching from one project to the other frequently.

4.4 Assessing uncertainty

Avalanche forecasting always has a degree of uncertainty to it. The challenge is to estimate where the uncertainty occurs, the degree of uncertainty and how to communicate this so that all parties involved have a clear understanding of the situation. One way to do this is described in Figure 4. One should also try to assess the critical sources of uncertainty in each project in the planning phase and consider building in an extra margin of safety in the OSARM if one expects a high degree of uncertainty during the operational phase. In Case 2, a lack of snowpack data resulted in many days with high uncertainty in the forecast.

5. CONCLUSIONS

Our experience shows that the operational specific avalanche risk matrix OSARM can be a valuable tool in object specific avalanche forecasting operations. The concept is flexible in terms of methods to conduct risk analysis, but one must consider both the exposure and vulnerability of the element at risk in the process.

Because the thresholds for danger levels are decided in collaboration with the risk owner beforehand in the planning phase, our experience shows that the risk owner has a better understanding for decisions during the operational phase. It is important that for every danger or risk level a consequence and mitigation measure is defined – the OSARM mitigation levels. This keeps the communication clear and reduces the likelihood of misinterpretation of the avalanche forecast by the receivers.

Furthermore, establishing these mitigation levels during the planning phase creates a strong collaboration with the risk owner which further leads to a better understanding of the avalanche forecast product delivered in the operational phase.

For the Meso (>10km ^{2}) scale Tyin-operation, we experienced that applying the framework described in the CMAH (Statham et. al 2017) using *sensitivity to trigger* and *spatial distribution* as the parameters for assessing likelihood of avalanches was producing good results. However, on a micro scale operation (< 1 km^2), i.e. where a single slope is considered, one also must consider other factors. These assessments have in fact many similarities to when a skier is evaluating a single slope. An interesting approach for the future could be to gauge different slope evaluation tools intended for skiers on how well they perform in a slope scale avalanche foresting scenario.

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