

DIGITAL TRANSFORMATION AS AN OPPORTUNITY FOR OPERATIONAL GENERATION CHANGE WITHIN AVALANCHE SERVICES

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ABSTRACT: In many areas of the Alps, there will be a generational change within the avalanche services over the next few years. This entails the risk of knowledge loss in the assessment of avalanche hazard and the resulting measures, especially when it comes to securing transportation corridors and settlements, where avalanches are often large but less frequent than in ski resorts. Although years of experience, local knowledge and "gut feeling" cannot be completely digitized, technological developments allow to process and store at least some of this valuable information in a structured format. This enables 1) the smoothest possible transition to new and existing members of the avalanche service, and 2) it minimizes the operational risk that can arise from a loss of knowledge. The avalanche service of the cantonal road authority in the Lower Engadine (Switzerland) assesses up to 200 avalanche paths spread over a road distance of approximately 200 km. The road connection of the Lower Engadine represents an important traffic route for industry, and tourism, in this region (up to 6000 cars on peak winter days). Meteorologically, the region is challenging as both west-northwesterly and southerly weather conditions can lead to significant snowfall and wind transport. Furthermore, the avalanche paths are distributed over a very large altitude range of 1000 - 3000 m.a.s.l. Using the example of Piz Chapisun (2930 m), known as the "Gonda avalanche", over 25 winter seasons were digitally processed from handwritten data, maps and relevant snow/weather events. The avalanche paths have a length of 1600 meters, and both dry and wet avalanches can endanger the road, railway, hiking trail and a cross country slope in the runout. All avalanche paths were analyzed based on different escalation levels, indicator avalanches and historical documentation. By exploring the operational applicability of a digital knowledgebase it is shown that this concept could be expanded to a large area with over 200 avalanche paths, and despite new measurement and detection data, human experience is still crucial in the digital transformation.

KEYWORDS: Knowledge transfer; digital database; data-driven decisions; generation change.

1. INTRODUCTION

Only limited information is available on the demographics, training and how (often decade long) knowledge was gathered within avalanche services in Switzerland (St. Clair et. al (2024)). Yet, in many areas of the Alps, there will be a generational change within the avalanche services over the next few years. This potentially results in a risk of operational knowledge loss, especially when it comes to securing traffic routes and settlements, where avalanches are often large but less frequent than in ski resorts. Moreover, this might lead directly to an enhanced risk for both the avalanche service itself and the people living in the related area. While the residents might be more prone to avalanche related accidents, the avalanche services are under enhanced pressure from a legal perspective.

Furthermore, for site-specific avalanche forecasting no common standard or method currently exists in Europe. This makes it challenging to digitalize and standardize knowledge transfer (Demmel et. al (2023)) within and across avalanche services. The European Avalanche Warning Services (EAWS) created guidelines on how to organize avalanche warning services that works at a site-specific scale (EAWS (2022)).



Figure 1: Avalanche control on 25.2.1970 running full path and reaching the road. The town of Lavin (Lavin translated means avalanche) can be seen to the right in the picture.

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With respect to these guidelines Langeland et. al (2023) used the term “forecasting” instead of “warning”. In Langeland (2018) a concept was presented linking the Conceptual Model of Avalanche Hazard (Statham et. al., 2017 and CAA (2016)) and extended to a risk based concept by considering the object at risk.

2. GOALS

This work aims to present and describe a concept that supports digitalization of decision making and knowledge transfer in avalanche services. The concept focuses on “operational useful data” to show existing decision-making procedures based on past avalanches and the meteorological environment leading to it. Additional information such as engineering reports are considered to potentially show site specific divergent decision thresholds.

The main goals are:

- 1) To incorporate all operational information on a single web-based platform for simple data access. The platform needs to supplement observations and data in a variety of (temporal and spatial) formats
- 2) Provide a framework to digitize relevant operational (objective but also subjective) knowledge.
- 3) Support the generational change and thus a person starting in the team to get an overview of the entire operation and its history easily with typical and generalized characteristics of areas and certain avalanche paths.

Secondary goals are:

- 1) Prepare the database that it can later provide data analysis and data driven learnings to supplement existing site-specific avalanche knowledge
- 2) Derive data based general rules to support the decision-making process.

3. METHODS

3.1 Establish context of operation

To understand decision making processes it is crucial to gain an overview of operational goals of the operation. Therefore, its organization (amount of people, roles and responsibilities) serves as a good starting point. This calls furthermore for an analyzation of the team itself in terms of size, responsibilities and training. External stakeholders and affected user groups (e.g. neighboring avalanche services, community, police, railway, etc.)

are important considerations as well. The legal mandate of the local team should be defined.

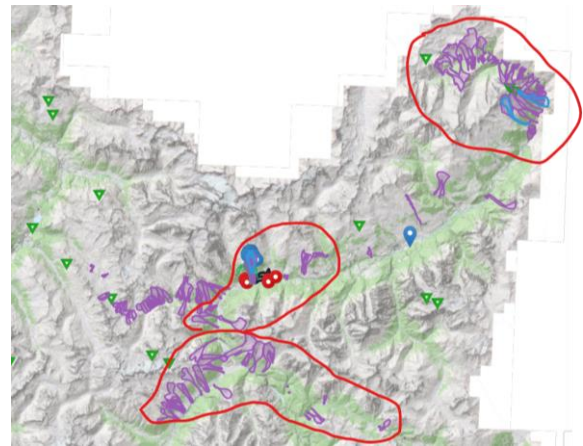


Figure 2: Overview of operational area of the cantonal road authority of the lower Engadine valley. Avalanche paths (violet), Automatic weather stations (green triangles), Gonda area (blue) and main forecasting sub-areas (red).

Especially for operations existing for a long time, avalanche specific information and data usually exists in a wide variety of forms. This could be engineering reports, pictures or mapping of historic events, defined avalanche paths, areas and objects at risk, closure times and existing measures. Depending on the site, the organization and the documentation, a lot of information is also stored in the memories of the people involved, finally leading to the (objective or often also subjective) decision-making process of the operators.

3.2 What events affect or reach the object at risk?

A general description of the areas and avalanche paths on a map overview is needed. General information for each path or area can digitally be collected as meta data assigned to avalanche paths. Especially for newer people on the team this can be very useful to get a general understanding of the paths, typical avalanches and consequences for the object at risk.

A general description of areas and avalanche paths involves:

- 1) Which avalanches (type; size; return period) typically affect the road.
- 2) Indicator avalanche paths: which ones? When do they typically release?
- 3) How much historical data exists? Can it be supplemented with other data such as satellite analysis of deposits? Are ava-

lanche recordings already available. Interfaces to existing other databases (avoid double entry!).

- 4) In which format does the data exist? (mapped avalanches, text-based event reports, pictures)

3.3 Which data is typically used during the hazard assessment?

To assess avalanche danger and thus to estimate hazards, different data is typically used as:

- 1) Existing automatic weather stations (AWS): Which AWS exist, which sensors are installed and which of these AWS measurements are operationally used?
- 2) Monitoring: Do monitoring solutions exist? E.g. geophones, infrasound, radar, cameras, laser scanners, etc.
- 3) Which numerical weather prediction models are typically used under which weather situation?
- 4) Which local observations are collected? Where are suitable observation points?

3.4 Which measures are taken?

The collected data and its interpretation finally leads to a set of different possible measures that can be used on their own but also in combination. These measures include closures, active avalanche control (helicopter control, remote avalanche control systems RACS, etc.), evacuations, etc. Each measure shows its own characteristics that need to be identified as, for example, where closing points are located. Moreover, measures need clear communication on who's responsible for the implication and why this measure was taken at a certain time/area. Finally different measures with different characteristics and implementations need to be communicated individually. The decision-making process leading to the used measure is often influenced by multiple factors.

3.5 What influences the decision for certain measures?

Based on historic knowledge some basic thresholds are typically used under which meteorological (e.g. wind speed and direction) and snow conditions (e.g. amount of snow in the path and new snow over 24 hours) certain paths can produce avalanches that might endanger an object at risk.



Figure 3: Example of recordings in table format and basic mapping.

Yet, more factors affect the final decision-making process such as past avalanches that already removed snow available for entrainment (positive effect) or smoothed the path and resulting in longer runouts (negative effect). Another important factor is for example the prevailing avalanche problem and thus the given snowpack stability. The available data is used for a forecast that is continuously refined or adjusted if needed based on direct observations of avalanches in indicator paths or by automatic detection systems. Changes in the data (e.g. in meteorological or snow conditions) can determine if measures must be taken earlier than initially forecasted.

4. EXAMPLE GONDA

The avalanche service of the cantonal road authority in the lower Engadine (Switzerland) assesses up to 200 avalanche paths spread over a road distance of approximately 200 km. The team consist of 2 permanent staff and 1 external adviser that is also taking an active role during the operation (e.g. forecasting, control measures, documentation). Engineers from the cantonal office for forest and natural hazards are advising and consulting the operational avalanche team with respect to possible mitigation measures and safety concepts.

4.1 Description of the Area

The south facing slopes from Piz Chapsiun (2930 m.a.s.l.) between Lavin and Guarda endanger the cantonal road, a winter hiking trail, a cross country slope and the railway (black lines) at around 1400 m a.s.l.. Three main release areas and paths, which all can reach valley bottom, can be identified from west to east: Val Punia, Urezzas and Gonda. The Gonda avalanche path is the most challenging one with a bowl shaped release area that funnels into a gully before opening in the lower part of the path.

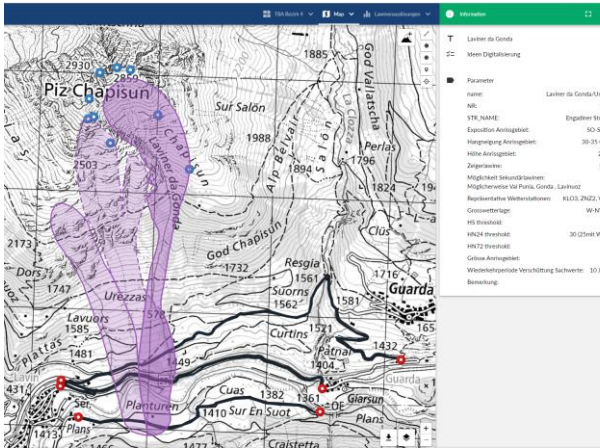


Figure 4: Avalanche paths Val Punia, Urezza and Gonda (violet) with path specific static meta data on the right. Closure points (red) and affected infrastructure (road, trail, railway) (black lines).

4.2 Available data & hazard assessment for Gonda

The forecasting team usually starts with an analysis of the entire area by combining the current snow conditions with the expected weather forecast (e.g. new snow, wind drift, temperature increase). They usually discuss three main sub-areas where conditions might get critical (Figure 1, red polygons). E.g. sector Ofenpass would be more affected by a southerly atmospheric flow whereas the other sub-areas and paths would be more critical during wind and new snow from the north-west.

Key measurements are provided by AWS upstream. E.g. AWS Gatschiefer is a good indicator for strong NW-winds leading to snow transport to the release zones of Gonda.

Monitoring systems exist at Gonda. A combination of geophones and radar monitors avalanche activity and will now be supplemented with a laser scanner mounted on the RACS in the release area, allowing to measure snow depth increase during the storm. A FlowCapt sensor measures snow drift by wind at the ridge.

Weather, avalanche events, snow conditions and measures such as road closures have been recorded and documented in a variety of ways. Since 1998 detailed summary reports have been made by one of the team members. These reports summarize the chronological chain of events and decisions. They are typically a combination of text, pictures of events or observations and measurements or numerical weather prediction data. Since 2006 notable events have been mapped digitally in different databases (StorMe and SLF).



Figure 5: Gonda avalanche path with example set of historic avalanches (blue), closure points (red) and affected infrastructure (road, trail, railway) (orange).

To supplement the data that has been collected, a SAR based satellite analysis (Tompkin et. al 2021) has been performed for two events in winter 2023-24. Especially for natural events this allows us to accurately map deposit sizes and runout distances. Figure 6 shows an avalanche event from 2023-12-02 (blue dashed line) and the according avalanche deposit mapped via satellite (red polygon). In this case it indicates that the actual deposit were mapped slightly too far to the west.

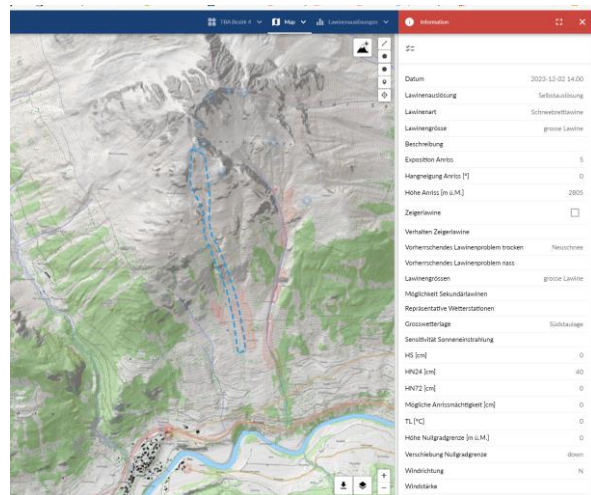


Figure 6: Combining different data sources of same event. Observed avalanche (blue), mapped deposits via SAR-satellite analysis (red). Entered data on avalanche and weather characteristics.

4.3 Measures at Gonda

To actively mitigate the avalanche hazard at the Gonda path, military weapons (mortars) had been used since 1975 until 2001. This measure was supplemented with helicopter control with explosives. In 2001 the first three remote avalanche

control systems RACS (Wyssen avalanche towers) have been installed in a pilot project. Five more towers were added in 2009 and one more in 2022.

On average the towers are used 8-12 times per season. A radar positioned at 2310 m a.s.l. looking upwards towards the release area supports the decision-making process. Its installation provides information on natural and controlled avalanche activity.

Specifically for the Gonda avalanche path road closures related to the time needed to perform control work have been reduced from around 1-1.5 hours (using the military mortar after 2001) to around 30 minutes per control mission (using the RACS). Until 2000 active control was only possible via helicopter and preventive closures lasted up to 2 days until the weather allowed for flying conditions.

4.4 Challenges at Gonda

Strong winds from NW can be a challenge and significantly load the release areas (also without intense snowfall in the direct area of Gonda). The automatic weather station Gatschiefer and the FlowCapt station at the ridge are closely monitored for that reason during storm events.

In recent years, strongly varying temperatures during a storm cycle have been a challenge. Significant rise in temperatures shortly after, or during, snowfall with rain over 2000 m.a.s.l. have been observed. Not only monitoring the altitude variations of the 0°C line over a period of hours or days but also the interpretation of the effects of these changes on the snowpack is challenging.

Although the installed RACS allow to release the snow in smaller portions and in a controlled way, forecasted vs. measured new snow amounts are challenging. In an example from 21.01.2018 the numerical weather prediction models forecasted 10-20 cm of new snow for the next 12 hours. Snow depth observations by the operators in the valley and with AWS on the mountain indicated that critical new snow amounts were reached much earlier than forecasted with over 50 cm in 5 hours. This resulted in earlier closures and control measures and shows how dynamic the decision-making process is.

5. DISCUSSION

5.1 Digitalizing data to facilitate the generation change

Combining static data (e.g. path characteristics) with dynamic data (e.g. mapped avalanche events, documented decisions, etc.) allows a new person to quickly get a “feeling” of the operation and specific paths. Especially overlaying different layers of information and being able to filter and focus on specific events can be a very intuitive process might have the potential to enhance the learning curve significantly.

5.2 Digitalizing the decision-making process

Whereas it is rather straight forward to identify the typically used data for the hazard assessment and forecast as well as the results of avalanche events, it is much more challenging to document the decision making leading to certain measures.

Combining and comparing static data from engineering reports with static data from the team members and also the difference between different dynamic data from different events might however give insights to the decision-making process in more depth.

Filtering and aggregation of data, e.g. showing all events that happened during snowfall events from northwest, allow to link weather and avalanche observations. The consequences of operations become more measurable for example: 1) effect of active avalanche control: more avalanches but less runout distances, and 2) documenting closure times and compare them from season to season.

For some operations the digitalization process resulted in a discussion about responsibilities of the individual members of the team. E.g. It was not always clearly known or defined that the person releasing an avalanche by explosives from helicopter can be personally responsible for potential damages. A clear workflow and decision making process on whom gives the final order for a certain operation can result in better coverage for the individuals.

5.3 Outlook

Additional data, i.e. the SAR based satellite analysis, allows to supplement the dataset with meaningful and objective data. This results in a database that is as complete as possible. Already now a large database of available satellite data exists, often more than 10 years back in time. Although this data is not available in real-time and often has days between the individual satellite overflights,

relevant information can be extracted for local avalanche commissions.

While it seems straightforward to connect different spatial and temporal processes, decisions and scales, the entanglement of this information, while reducing redundancy in a digital way possesses a challenge. This challenge does not only arise from a technical site but also needs a deep understanding on avalanche formation and decision making.

6. CONCLUSIONS & OUTLOOK

It was found that the digitalization process in general is a good opportunity to critically rethink established workflows and structures for the local avalanche control team.

A combination of a variety of different information sources in a single platform that allows to filter and display data is useful for newer people but also simplifies the daily workflow for the entire operational team.

For forecasting in general, but especially for site-specific forecasting, there seems to be a need for standardizing the terminology and definitions used as in Schweizer et. al (2023) and EAWS (2023). Standards and norms such as ISO31000 for risk management can provide a helpful and general framework.

Studies have been initiated to quantify the demographics of current avalanche services and identify distinct needs, facilitate knowledge transfer and support succession planning (St. Clair et Al. 2024)).

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REFERENCES

- CAA. Technical Aspects of snow avalanche risk management – Resources and Guidelines for Avalanche Practitioners in Canada. Campbell, C., Conger, S., Gould, B., Haegeli, P., Jamieson, B. and Statham, G. Canada; Avalanche Association, Revelstoke, BC, Canada
- Demmel, S., Meier, B., Wyssen, C., Steinkogler, W. Digital transformation of ski resorts and community avalanche services – operational examples from Switzerland. In: International Snow Science Workshop Proceedings 2023, Bend, USA.
- EAWS 2016, Site-specific avalanche warning, Definitions and Recommendations. Visited 30.08.2023: [Site specific avalanche warning in Europe – EAWS \(avalanches.org\)](https://www.eaws.org/)
- Langeland, S., Velsand, P., Solemsli, L., Steinkogler, W. An Operational Specific Avalanche Risk Matrix (OSARM): Combining the Conceptual Model of Avalanche Hazard with risk analysis and operational mitigation strategies. In: International Snow Science Workshop Proceedings 2018, Innsbruck, Austria.
- Langeland, S., Steinkogler, W. Assessing the likelihood for each avalanche size in site-specific avalanche forecasting. In: International Snow Science Workshop Proceedings 2023, Bend, USA.
- St. Clair, A., Haegeli, P., Steinkogler, W., Winkler, M., Gasperi, A. and Schwarz, J. Differentiating contexts across European avalanche commissions to support future development: A call to action, in: Proceedings of the International Snow Science Workshop, Tromsø, Norway, 2024.
- Schweizer, J., Reuter, B., Mitterer, C. Towards a dictionary of avalanche forecasting - Describing some key terms. In: International Snow Science Workshop Proceedings 2023, Bend, USA.
- Statham, G., Haegeli, P., Greene E., Birkeland, K., Israelson, C., Tremper, B., Stethem, C., McHahon, B., White, B. and Kelly, J., 2017: A conceptual model of avalanche hazard, Nat
- Tompkin, C., Leinss, S., Backscatter Characteristics of Snow Avalanches for mapping with local resolution weighting. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, VOL. 14, 2021