AVALANCHE ACTIVITY MONITORING AND ALARMING AT MOTTEC, VALAIS, SWITZERLAND – A COMBINED APPROACH TO ENSURE CONSTRUCTION SITE SAFETY

Ólafur Stitelmann[1*], Théo St-Pierre Ostrander[1], Maxence Carrel[1], Ivan Sanchez[2], and Marc Délèze[3]

1 Geoprevent AG, Switzerland
2 HYDRO Exploitation SA
3 Patrick Epiney Ingénieur Sàrl

ABSTRACT

The Mottec power plant is part of the hydropower facility operated by Forces Motrices de la Gougra, located in the Val d'Anniviers, Valais, Switzerland. It is a high head (600 m) pump-storage power plant with water stored in the Turtmannsee reservoir. Renovation works to a subterranean penstock require regular helicopter flights to transport and unload material in a zone exposed to avalanche hazard. The unloaded material must then be moved within the access tunnel leading to the penstock. Uninterrupted operation of the construction in winter is key to the progress of the renovation works. Local avalanche experts set up a safety concept stating that during days with avalanche danger 4 or 5, none of the workers are allowed to exit the tunnel. To be able to work during avalanche danger 3 days, an avalanche radar connected to alarming units was installed and operated in the 2025 / 2026 avalanche season. The alarm system uses Doppler radar to detect avalanches by analyzing reflected waves. When an avalanche occurs, the reflected signal returns to the radar at a different frequency than the emitted signal. This frequency shift enables the system to calculate the avalanche's velocity, and location by applying additional processing based on signal travel time. Once detection occurs alarms are activated so affected workers can evacuate the construction site, and exposed roadways can be closed. The zone being monitored lies at an elevation significantly higher than the sites requiring alarm response, because of this, there is ample time to react. Detection and alarming additionally support mitigative and forecasting efforts as event verification, or lack thereof steers the response in terms of mitigative actions. These combined factors have expanded the operational setting for construction and maintenance works which can occur at avalanche danger 3 level. This illustrates adaption and innovation to meet the increasing demands on vital infrastructure through utilizing state of the art technology in parallel with proven forecasting and mitigation schemes.

KEYWORDS: Avalanche Radar, Alarming System, Hydro-power plant.

1. INTRODUCTION

Hydropower represents about 60% of Switzerland's electricity production, it is therefore a pillar of the country's economy and plays a crucial role in supplying power to households (Boes et al., 2021). Being an Alpine country, many damns are built in upper catchments designed to regulate discharge, which in turn supports optimizing power production and flood mitigation during high-precipitation and severe snowmelt events. A network of pipes and penstocks connects dams and reservoirs, ensuring the transfer of water between catchment and increasing the capacity of water management. The reservoir in Mottec (Val d'Annivier), is supplied by both the Navisence river and by an underground pipe connecting the reservoir to the neighbouring Turtmann catchment. In summer, the pipe is full, while in winter it is empty, making renovation works of the pipe only possible in winter. Two tunnel entrances leading to the pipe exist in the Val d'Annivers, one located at the bottom of the valley, near the Mottec reservoir, the other is located higher up-slope is typically accessed by helicopter. The higher entrance is also the one used to bring material in the tunnel with the help of helicopters. A landing platform has therefore been built next to the tunnel entrance. Nevertheless, the landing platform and the tunnel entrance are inconveniently located in an area highly exposed to avalanches. Mitigating the avalanche risk is therefore vital to increase the safety of workers, as well as to optimize the renovation work and reduce overall costs. As construction measures are costly and require long design and installation phases, the implementation of an avalanche alarming system was chosen. In Switzerland 5 avalanche dangers exist. The alarm system makes the construction site safer for levels 1 and 2, while enabling work to continue during level 3 conditions. When levels 4 & 5 are reached, the renovation works are stopped. The alarm system consists of an avalanche radar monitoring the avalanche-prone slope above the landing ground and transmitting an alarm in near real-time to alarm horns located at both entrances of the tunnel. When the alarm is activated, the workers must evacuate the landing ground and take refuge in the tunnel.

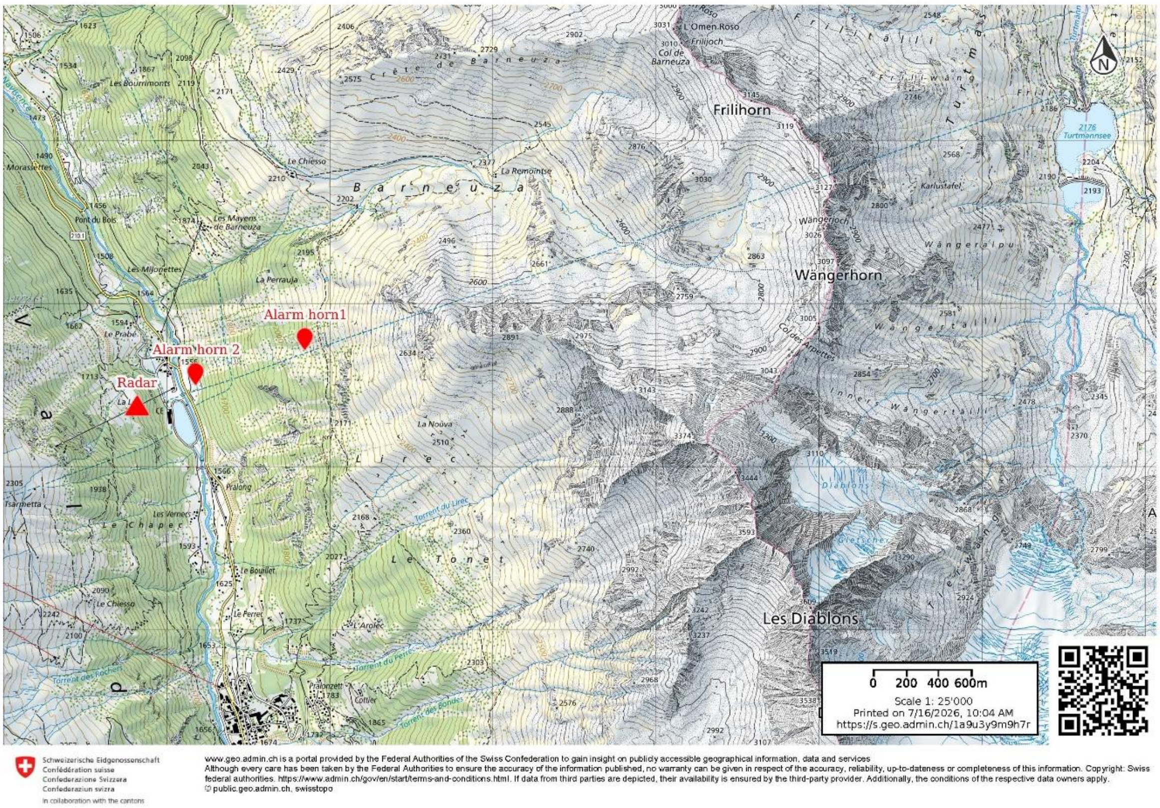

Figure 1: Site overview showing general site location (top) and the location of the monitoring and alarming equipment (bottom) (source : SwissTopo).

2. SYSTEM AND SITE OVERVIEW

2.1 The AVYX Avalanche Radar system

The AVYX avalanche radar makes use of the doppler effect to locate and track avalanches. The radar can be integrated into a monitoring system, or into an alarming system as in the case in Mottec as it is connected to alarm horns in the field. The radar sends out radio waves at a frequency between 10.0 and 10.6 GHz. The opening angle of the radar in Mottec is about 30°x30° (horizontal x vertical). There, the horizontal angle is reduced due to the external antennas, nevertheless external antennas permit an increase in the resolution of detectable avalanches at longer distances. The main advantage of the radar as a monitoring or alarming technology for avalanches is the capacity to monitor several avalanche tracks remotely and simultaneously, in all weather conditions. Radio-waves can travel through poor weather, and the radar is equipped with an anti-snow system to keep it unobstructed during snowfall or wind events.

The AVYX avalanche radar measures continuously. When the system detects an avalanche, the integrated PTZ (Pan-Tilt-Zoom) camera is automatically triggered to document the event with optical images or videos. The radar monitors and tracks avalanche activity in real time until the event comes to rest or moves beyond the radar's field of view. All recorded data are transmitted to the GRAVX platform for online display and analysis. In addition to event tracking, the system provides derived parameters such as avalanche start time, duration, size, and average front velocity. Configurable SMS and email alerts enable operators to be notified immediately when an avalanche is detected, completed, or enters predefined alarm zones

2.2 Data transmission

Data transmission plays a central role in the performance of alarm systems. By definition, an alarm system needs to detect events and emit an alarm as close to real-time as possible, while the number of false alarms must remain acceptable. For the AVYX avalanche radar, this means that data must continuously be processed locally. In addition, the system must be able to automatically determine whether an event must trigger an alarm and be able to safely transmit the alarm signal to the alarming device. An error at any stage of this process compromises the alarm system and can result in false negatives. Redundancy in power supply and signal transmission between each component strongly reinforces the reliability of the overall system. To minimize the number of false positives, one can either optimize the calibration of detection parameters or draw regions of interests. The former permits signal exclusion based on its main attributes (e.g. signal-to-noise ratio, duration, average speed, etc.). The latter focuses the analysis on pre-defined avalanche prone regions and excludes signals in surrounding regions. This can, for instance, significantly reduce the false positive rate due to aerial vehicles or birds. Both strategies require the system operator to be able to access the data processing unit remotely. Alarming devices such as alarm horns must also be remotely reachable and controllable to reduce the nuisance of alarms induced by false positives. Ultimately, regular health checks of the sensor itself, here the AVYX radar, are necessary for predictive maintenance.

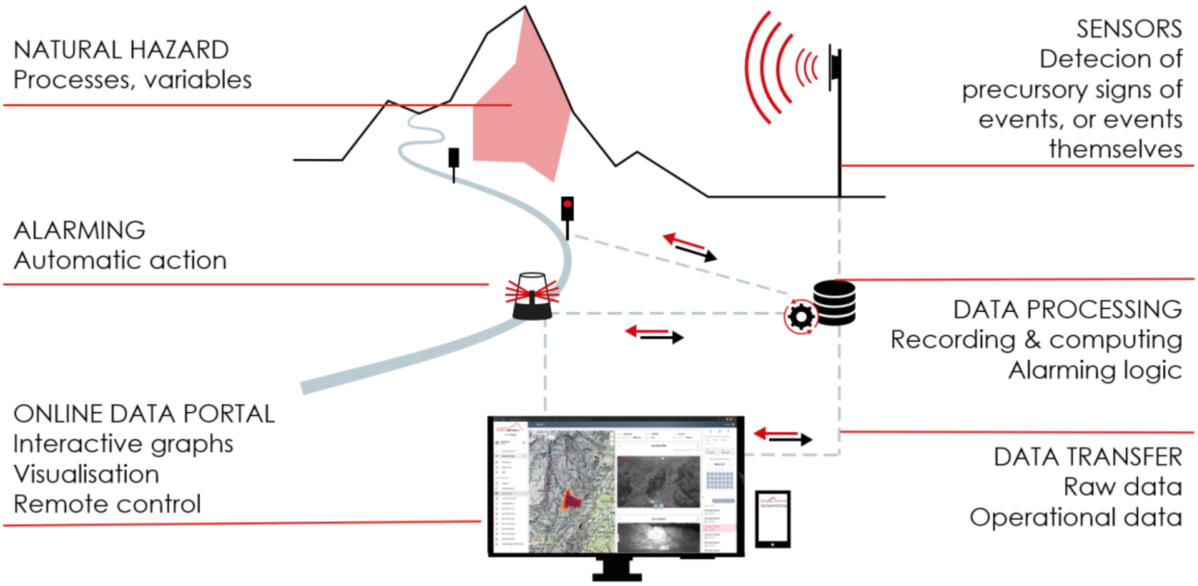

Figure 2. Design of a typical alarming system, including data and signal transfer between local and backend components.

In the case of Mottec, communication between the control unit at the radar location and the alarm horns is redundant. Direct line-of-sight makes a radio link possible despite both components being at opposite sides of the valley. Mobile network with 4G coverage constitutes the back-up link for alarm transmission. The control unit is reachable by Geoprevent through this same 4G network. All components of the alarm system could be supplied with 230V grid power, which has proven to be a stable solution so far.

An alarm system performs well if it can respond to an event in near-real time. When an avalanche happens, the alarm system performs two main steps impacting the response time.
The first step is the detection of the event itself. The radar emits waves at 10.0-10.6 GHz every second and calculates the location and velocity of the moving objects based on the Doppler effect. A couple of seconds are therefore needed for the radar to identify a moving object. Then, to minimize the number of false positives, the radar tracks the moving object in order to insure the event is indeed an avalanche. The time necessary for this phase highly depends on the calibration of the radar and is site-dependent. If the signature of the event (Signal-to-Noise-Ratio, duration) is confirmed to be an avalanche, the control units sends out an alarm to the alarm horn. Hence, the second steps impacting the response time of the system is the transmission of the alarm signal to the alarming units. The quality of signal, radio or mobile network, can impact the duration of the alarm signal transmission. The duration of the second step is therefore also site dependent. An alarm system is only relevant if the time between the alarm activation and the avalanche is sufficient to permit people and mobile assets to take refuge. In the case of Mottec,

the workers are given the instruction to run to the tunnel entrance as soon as they hear the alarm horn.

2.3 System location

One of the main challenges for installation in Mottec was to find a suitable place for the radar. The radar performs best when expected movements in line of sight, relative to the radar. In addition, it is preferable if the installation site has access to grid-power. Further, to ensure transmission of the radio signal, the installation site must have a direct line of sight to the alarming units at both entrances of the tunnel. Based on these criteria, the first tower of the cable-cable car located on the opposite side of the Valley was chosen (Figure 2). The cable car is rarely used and has little impact on the performance of the radar. Placing the radar on top of the tower also permits a clear view over the area to monitor and both entrances of the tunnel. The distance to the avalanche release areas and the radar is acceptable (max. 2.15 km). Even though some areas are hidden by topographic shading, the Signal-to-Noise-Ratio is overall satisfactory for the most active release areas above the tunnel's upper entrance.

Figure 2 Aspects of the radar monitoring location showing hardware, tower to which the radar was mounted, and the mobile alarm system

2.4 Data visualization on GRAVX online platform

The control unit located near the radar is reachable by 4G mobile network. This supports both the operator control of system components, and visualization of the radar data on the GRAVX online platform (Figure 3). There, event attributes (date/time, duration, length, size, speed, classification) are shown together with event images and avalanche trajectories projected on a map. Events can be filtered based on the above-mentioned attributes and exported to .csv format. The user can also navigate to the live view to take control of the PTZ camera. The platform can also be used to communicate between users or with the Geoprevent support team. Depending on user level, recipients' lists of SMS alerts can also directly be edited on GRAVX.

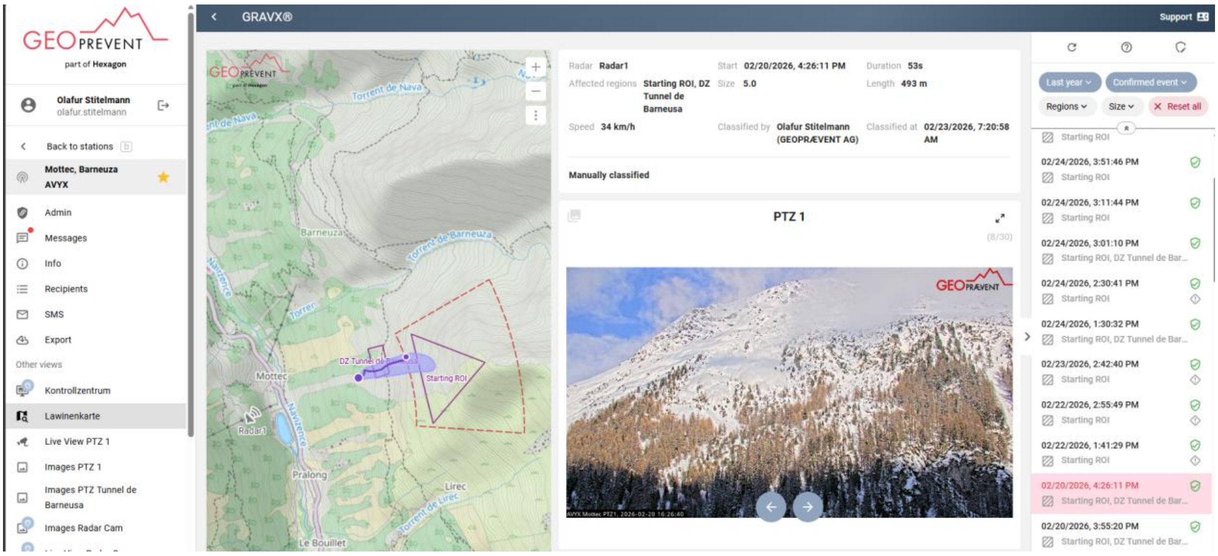

Figure 3 The visualized output of a detected event in GRAVX

3. RESULTS (DATA VISUALIZATION, ALARM TRANSMISSION)

3.1 Summary of 2025-2026 season

The system detected 69 events during the 2025-2026 season, between 27.11.2025 and 09.04.2026. Of these, 68 were avalanches, and 1 was likely caused by a flying object. 11 avalanches reached the upper entrance of the tunnel; all these avalanches happened in the middle of winter between 29.01.2026 and 24.02.2026. The avalanches reaching the tunnel entrance were large avalanches, with a length ranging between 490m to 1km.

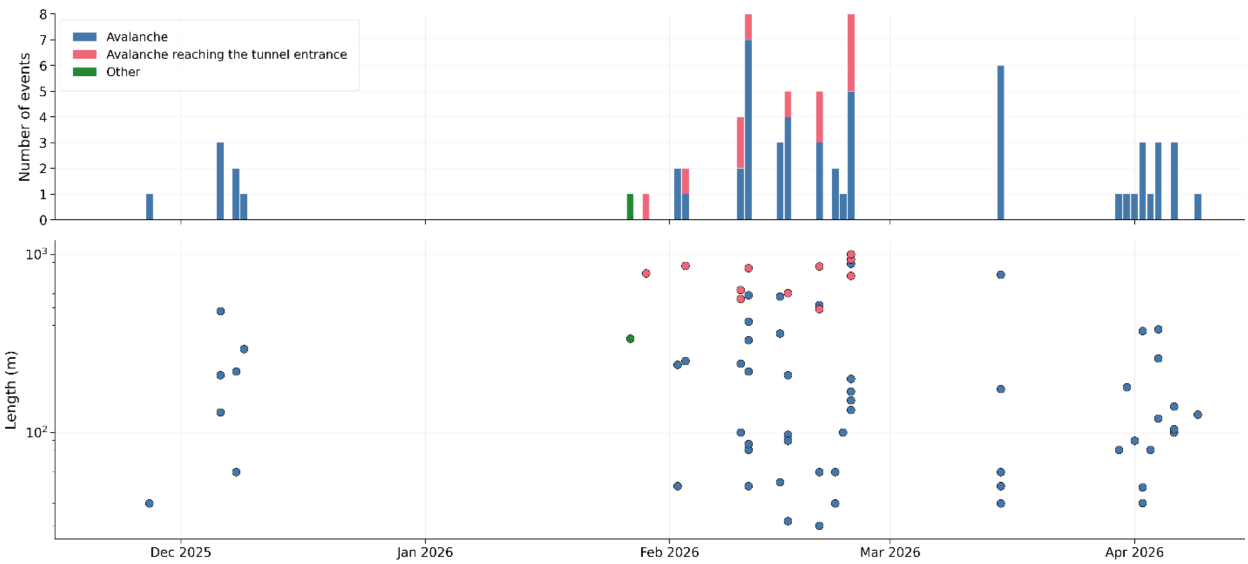

Figure 4: Overview of the 2025-2026 season. Avalanches are plotted in stacked columns for number of events per day while avalanche lengths are plotted with points. Orange columns and points correspond to the avalanches reaching the upper entrance of the tunnel.

3.2 *The 20.02.2026 event*

Among the 11 avalanches reaching the upper entrance of the tunnel, the 20.02 16:26 avalanche was one of the biggest events. The alarm system performed as planned and the alarm horns were activated 6.724 seconds after the start of the event, leaving about 21 seconds reaction time on site. When this event happened the avalanche danger was at 4, hence no workers were present on site.

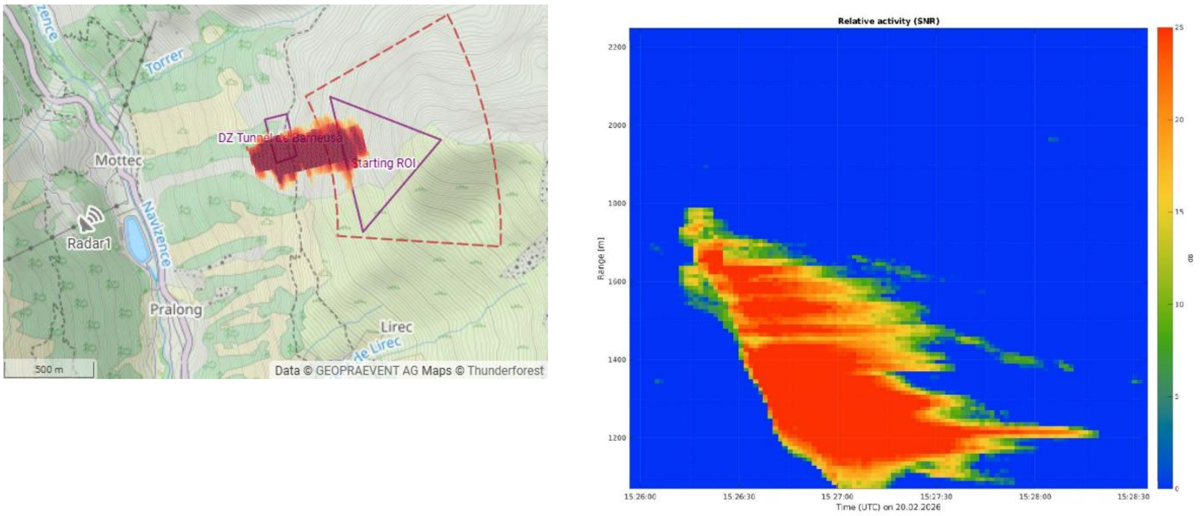

Figure 5: The signal perceived from the 20.02 16:26 avalanche reaching the upper tunnel entrance projected on a map (left) and distribution in time (right side, vertical axis is range from the radar, horizontal axis is time).

4. CONCLUSION AND DISCUSSION

Results of the 2025-2026 season show that the system performed very well with only one false positive. The alarm response time (under 10 seconds) is aligned with the requirements of the local safety plan and could hardly be decreased without compromising the performance of the system in excluding false positives. Nevertheless, flying objects remain a challenge for the radar system as they can be confused with avalanches. When calibrating detection algorithms in order to exclude these events, one must be aware that such events can happen simultaneously to avalanches, making unsupervised discremination more difficult (Figure 6).

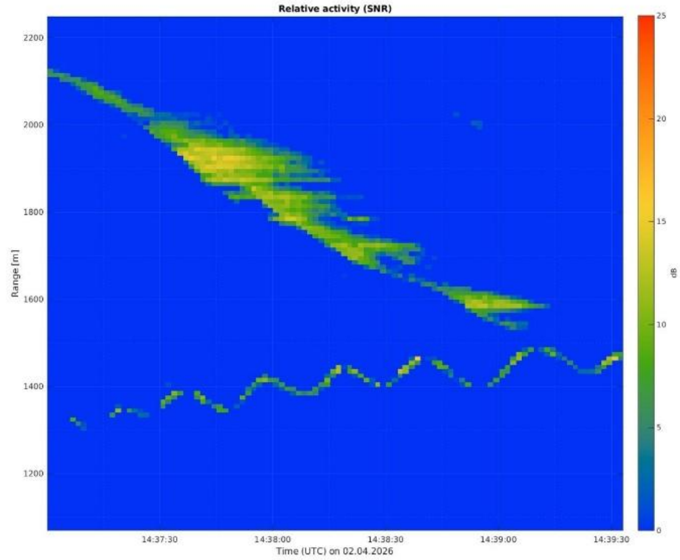

Figure 6: the radar signature (Signal to Noise Ratio) of a paraglider (lower oscillating signal), and an avalanche. The horizontal axis shows time whereas the vertical axis shows distance to the radar.

Operational aspects of the system could also be reinforced. For instance, one could implement redundancy in power supply to ensure the operation of the radar in case of grid power shortage. Regarding communications, in case of a general mobile network blackout in the valley, access to the control unit would be compromised. Despite the alarming system continuing to be operational locally, data could not be visualized on the GRAVX online platform anymore.

Over the 2025-206 winter season, the alarming system based on the avalanche radar permitted to increase the safety of workers at the tunnel entrances. The system has proven to be reliable and has subsequently led to an optimization of the renovation costs in two ways: work could be maintained while the avalanche degree was 3/5, and the likelihood of costs related to potential avalanche accident was reduced. Further, the avalanche radar has produced valuable data on the avalanche activity and avalanche behavior for the monitored slope. This data could in turn be used for designing protection measures or ameliorate avalanche modelling research.

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